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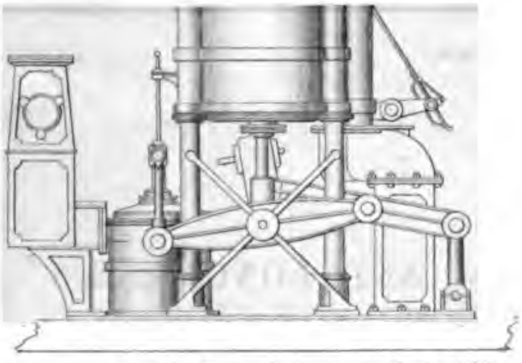

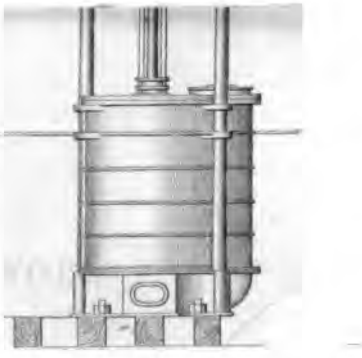

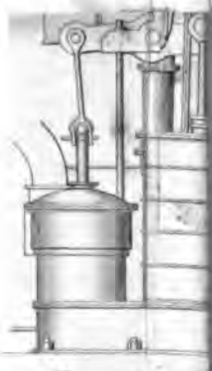

UNIV. OF MICH.

11/10/16

TREATISE

ON THE

STEAM ENGINE

IN ITS APPLICATION TO

MINES, MILLS, STEAM NAVIGATION, AND RAILWAYS.

By the Artizan Club.

EDITED BY

JOHN BOURNE, C.ivil E.ngineer

ILLUSTRATED BY

THIRTY-THREE PLATES, AND THREE HUNDRED AND FORTY-NINE ENGRAVINGS ON WOOD.

NEW EDITION.

LONDON:
LONGMAN, BROWN, GREEN, AND LONGMANS,
PATERNOSTER-ROW.
1851.

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New-street-Square.

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TO

HER MOST GRACIOUS MAJESTY

THE QUEEN,

THIS TREATISE ON THE STEAM ENGINE BY THE ARTIZAN CLUB,

DESCRIPTIVE OF THE STRUCTURE AND PRINCIPLES OF ACTION OF

THE GREAT MECHANICAL AGENT

WHICH HAS FOUGHT THE BATTLES OF THE EMPIRE, AND NOW SUSTAINS ITS GREATNESS;

WHICH BINDS NATIONS TOGETHER IN AMITY,

ANNIHILATES DISTANCE, SOFTENS NATIONAL PREJUDICES, AND PROMOTES CIVILISATION;

WHICH BRITISH ARTIZANS HAVE BROUGHT TO ITS PRESENT PERFECTION,

AND

WHICH BRITISH ARTIZANS NOW ASPIRE TO ILLUSTRATE,

IS,

By Her Majesty's Permission,

MOST RESPECTFULLY INSCRIBED,

BY

HER MAJESTY'S OBEDIENT SUBJECT AND SERVANT,

JOHN BOURNE.

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1851

PREFACE

TO THE FIRST EDITION.

THE present Work makes its appearance under many disadvantages. The circumstance of having been published in monthly numbers furnishes, of itself, an explanation of many imperfections; for it can hardly be expected that works produced under the exigencies of periodical publication should be distinguished by the perfections which belong to literary leisure and fastidious elaboration. The time which the practical engineer can devote to literary undertakings must, under any circumstances, be inconsiderable, and the late pressure in the engineering world has further abbreviated this precarious leisure. I have been obliged to confide the greater portion of the theoretical part of the present work to some mathematical assistants, whose algebra has, I fear, sometimes risen to a needless luxuriance, and in whose superfine speculations the engineer may perhaps discern the hand of a tyro. The makers of steam engines, again, have, for some time past, been so overwhelmed with work, that the drawings and other particulars of their machinery, which they had signified their willingness to furnish, they have in some cases been unable to send early enough to come in at the proper place; and faults of arrangement have been rendered inevitable by these irregularities, which I could neither rectify nor control. I do not mention these impediments to a more perfect execution as an excuse for any faults the work may contain, which I am sensible cannot be materially extenuated by such pleas; but I wish merely to suggest, that the demerits of an author or editor are not fairly measurable by the demerits of his work, when many of those faults have had their origin in the unpropitious circumstances of its production. In spite, however, of its imperfections, I believe that the present Treatise on the Steam Engine is likely to prove the most useful yet published; and it is the only one, I believe, which can be regarded as of a really practical character. Although falling far short of my conceptions of what such a work should be, I believe that it substantially fulfils the promise held out in the prospectus; and having now collected the rough materials, I trust to be able, should another edition be called for, to clear them of the dross by which they are now disfigured, and present them in a form that will in some measure justify the public approbation. In the haste of publication several errors have gained admission, the more prominent of which are noticed in the errata. I am by no means insensible to the importance of rigid accuracy in works of any scientific pretension; yet, inasmuch as I believe the errors of the present work will be found to be errors, not of ignorance, but, at the worst, of haste or inadvertence; as they inculcate no false views, involve no dangerous fallacy, and, for the most part, carry their own correction, I believe that they cannot materially diminish the utility of the work, or impair the authority of its statements.

The success of the present work, in a commercial sense, has long been put beyond doubt by the circulation it has reached; and from the press it has received a greater measure of praise than, I fear, its merits justify. The preliminary and practical portions of the work have, for the most part, been executed by me, the disquisitions upon the slide valve and parallel motion are taken from the "Artizan," and other portions of the work are by various members of the Artizan fraternity. In the practical part of the work I have been able to obtain but little assistance from previous authors, and many of the subjects discussed are now brought for the first time before the public. Mr. Farey's work, though of great merit, gives but little information of any kind touching modern engines; and Tredgold's work is chiefly made up of mathematical sublimities, which have but little relation to practice. From this judgment must be excepted the admirable description by Mr. Robert Stephenson of his locomotive engine, contributed to Tredgold's work; but the utility of that description is greatly diminished by the changes introduced into the locomotive engine since the time it was written, and by its own speciality, which, in the first instance, was its highest merit. The treatises of Dr. Lardner and Mr. J. Scott Russell upon the steam engine, though most creditable performances, come scarcely under the denomination of practical works, and the same remark applies to the treatise by Pambour; so that the domain of practical detail appears to have been but little explored by engineering authors, or, if explored, the public have not profited by the research. The practical part of the present work may, therefore, be regarded as a first attempt; and if the difficulty of the undertaking be consequently greater, so should the lenity be with which it is regarded.

To the leading engineers of the country my acknowledgments are due for the drawings they have furnished, and the many aids they have lent to the present undertaking. I have also to acknowledge the kind aid and encouragement afforded by Sir Robert Peel, through whose friendly offices Her Majesty's patronage was first given to the work, and through whom the permission is now conveyed for its Dedication to Her Majesty. The Artizan classes will, I am sure, appreciate these courtesies—for to them are they addressed.

JOHN BOURNE.

April, 1846.

PREFACE TO THE THIRD EDITION.

The demand for this work having exceeded my expectations, and I fear I must also say its own deserts, I have made an attempt in this edition to introduce such improvements as will render it more deserving of the public approbation. In the introductory remarks upon the subject of boilers, and in various other parts of the work, much improvement will be visible; and I have introduced some additional plates and cuts, with the view of bringing up the information the work contains to the present state of science. No work more speedily becomes antiquated than a Treatise on the Steam Engine; but this result, it is obvious, may be in a great measure obviated when a new edition is called for every year.

On a former occasion I expressed my acknowledgments to the leading engineers in the country for the many aids they had lent to the present undertaking; but there are still some persons who place their trust in secrets, and who can afford no more charitable supposition, when they see an acquaintance with steam machinery exhibited, than that their secrets must have been filched by some clandestine process. Some of these persons have been making insinuations in reference to this work, which I shall not notice farther than to say that if set before the public, the revelation would render them but slender service, and their prudence will probably suggest the inexpediency of such an exposure. It is a presumption at least, that a work is useful, when the main objection brought against it is that it tells too much; and those only can impute such a fault, who will not understand that it must be by other means than by the aid of certain recipes of perfection, that eminence is to be perpetuated or attained.

JOHN BOURNE.

London, December 20th, 1848.

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A TREATISE ON THE STEAM ENGINE.

PRELIMINARY DISCOURSE.

A TREATISE on the Steam Engine would, we suppose, hardly be reckoned orthodox if it began in any other way than with an account of the doings of Savery, Papin, and the other patriarchs whose names figure in the history of steam invention. The devices indeed of these ancient worthies bear very little resemblance to the modern steam engine, and can throw but little light upon its structure or mode of operation; but it was out of these primitive contrivances that the modern steam engine arose, and they derive a sufficient dignity from that relationship to make them the objects of a just curiosity. We think, therefore, that some slight sketch of the expedients employed in the early career of steam improvement is but a reasonable prelude to a Treatise on the Steam Engine, and is indeed indispensable to the integrity of such a work: But we fear our qualifications for the task are by no means so conspicuous, for delineations of this kind require a light and graceful pencil, and become intolerable in the hand of a vulgar limner. The great art lies in saying just as much as the necessity of the case requires, and nothing more; for a history of the steam engine is the least important part of a treatise on that subject, and only deserves a space answerable to its insignificance; whereas by needlessly expanding this part of the work, or by elaborating trivial schemes into importance, the proper subordination of objects is destroyed, and all those discriminating shades are obliterated which constitute the excellence of the picture. To all this we must add that people in these utilitarian days have neither time nor inclination to listen to long-winded descriptions of exploded projects in steam machinery, though they might like well enough to know something of the nature of those expedients if it can be told them in a few words: But they are not likely to perplex themselves with such inquiries as, who first forced water above its level by steam pressure, or solicited it to rise by a partial vacuum? and to say the truth, such inquiries appear to us of about as much importance as the researches of those learned grammarians, who spend a lifetime in restoring a dative case, or adjusting a metre or an accent. The task, too, of resolving these frivolous problems is quite as tedious a one as that undertaken by the learned persons aforesaid; for after having ascended through history, by a most toilsome progress, to the first person guilty of disturbing the equanimity of water by steam pressure, the shade of some learned recluse who flourished in ancient times in China it may be, or Japan, will probably rise up with proofs of a still higher priority, and the idol just set up for universal adoration will be cast into the dust by this new authority, to be overthrown in its turn by the researches of subsequent enquirers. The fact appears to be, that the power of steam to raise water above its level was widely known in very ancient times, and appears to have been occasionally employed by the Greeks and Egyptians for trivial, or rather for unworthy, purposes: But it is in modern times only that steam has been adapted to ends of weight or utility, and the history of the steam engine properly begins with that application.

It is not to be expected that the historical narration on which we are about to enter should contain much that is new. The facts with which we must necessarily deal have often been stated before, and we believe now admit neither of much increase nor modification; but it is not impossible, we think, to set these facts in truer lights, and to deduce from them sounder conclusions than have yet been realised. It appears to us to be a vice of many commentators, that they have attached too much importance to the deeds of individual projectors, and have estimated at far too low a rate the current intelligence of the time, of which indeed the proficiency of those exalted persons is to be regarded as merely the exponent. They have set down the early progress of the steam engine as due altogether to the perspicacity and contrivance of a few solitary adventurers, without hinting that some part of it might reasonably be ascribed to that spread of information and general advancement of knowledge to which that progress is in truth mainly attributable. The consequence of this fault is, that a host of projectors are made to 'shine aloft like stars,' whose merit, when tested by the general information of their own time, fades into insignificance. They stand, it is true, in the van of improvement, but the elevation due to the existing state of society is measured as a part of their intellectual stature; and while they are each presented to the imagination like a precipice starting abruptly to the skies in solitary and awful majesty, they are in truth only to be regarded as so many heights, which, whatever be their absolute altitude, rise only a few feet above the other heights around them. It is absurd, therefore, to seek to elevate any of the early projectors of the steam engine into greatness, for they were one and all persons of only ordinary intelligence and assiduity, of which every age has produced its thousands; and the progress they made was owing rather to the natural flow of events than to any great genius or foresight on the part of any one of them. It is still more idle to set down any one of these persons as the *inventor* of the steam engine. Great inventions are necessarily of a slow growth, and are rarely the produce of individual minds, but require time and experience as well as ingenuity to bring them to maturity, and indeed the happiest steps are sometimes the effect of accident. In the intellectual as in the material world, the most precious productions are those which cannot spring to perfection at once, and it would be as reasonable to inquire to what refreshing shower, or to what gleam of sunshine, the stature of a stately oak is attributable, as to what individual mind we are indebted for the creation of our modern steam engine. The exertions of different minds are merely so many agencies that have been happily conducive to a great result; and it would be as just to assign the invention of our modern men-of-war to Jason, as to assign the invention of the steam engine to Savery or De Caus.

But whatever be the merit that is due to these 'sons of notoriety,' it is we think divisible only among those of them who have been instrumental in working out some practically useful result. The mere men of speculation, who have suggested modes of doing things, but have never done them, are not to be ranked with those who have really accomplished something, in a case where the whole difficulty of the task lies in its practical achievement. Whatever else these ingenious persons may be, they are certainly not among the number of the improvers of the steam engine; and their claims, if to be considered at all, ought in strictness to be considered as the claims of a distinct class of persons. Nor can the merit of such a class, under ordinary circumstances, be considerable, for there is nothing more easy than to originate vague ideas of improvement, though it is generally a very difficult thing to carry those ideas into successful practice. M. Arago, however, and his followers it seems, have set the steam engine down as a French invention, because Solomon de Caus first adopted the idea of steam as a motive force, and Papin suggested the application of the cylinder and piston. It would be as reasonable, in our apprehension, to set down the battle of Waterloo as a French victory, because Napoleon adopted the idea of fighting it; for the question in all such cases is, not who first adopted an ideal result, but who actually realised that result in practice. The scheme of Solomon de Caus was neither useful nor new, and Papin's project was so impracticable, that he himself abandoned it in favour of Savery's scheme. We have no evidence that either of those persons ever completed an engine of any kind. Papin's scheme, as he first proposed it, was worse than the previous project of the Marquis of Worcester, for it was without a boiler; and after several gyrations he certainly left the steam engine in as imperfect a state as if he had never meddled with the subject. If, therefore, we were disposed to retort upon M. Arago his pitiful nationality, we might with some plausibility say that his proofs only show the lamentable barrenness of the French intellect; for the very ideas which, in the minds of Englishmen, have quickly grown up to a rich maturity, and have blessed all nations with countless new enjoyments, have, when implanted in the minds of Frenchmen, invariably failed to produce any useful result. But this is idle. The steam engine happens, no doubt, to be from first to last an English invention; but that result, we conceive, is not so much to be attributed to the superior genius of the English people as to the force of circumstances, which made some such instrument as the steam engine more valuable to England than to other nations. If France had possessed valuable mines lying under water, and at the same time an abundance of coal ready to be made instrumental for their recovery, there is every reason to suppose that the steam engine would have been a French invention; and we think the consideration that our honours are the result merely of accident, ought to reconcile that ingenious people to a priority it is idle to contest. No nation can be expected to excel another nation of equal power and intelligence in every thing; and if it be the fact, as we willingly admit, that the French excel us in some things, they must be content to give us the palm in others, one of which certainly is steam engineering.—There is no end, however, of these speculations, and we fear they are neither very captivating nor very convincing; so that we shall here cut them short, and proceed without further preamble to the history of the invention.

The history of the steam engine is divisible into five great epochs. The first extends from the times of the ancients to the first effectual application of the boiler, which appears to have been accomplished by the Marquis of Worcester, and it was this single step that turned the toys of Hero and De Caus into a true and useful steam engine. The second epoch is distinguished by the employment of a vacuum as an aid to the simple pressure of the steam. The third epoch relates to the successful application of the cylinder. The fourth to the condensation of the steam by injection, to the movement of the valves by the engine, and to the various improvements in detail, which were carried into effect by Smeaton. The fifth epoch is that distinguished by the application of the condenser, and the other improvements of Watt, which brings down the history to our own times; as since the steam engine left the hand of Watt, no improvement involving a new principle has been added to the list. Under each of these heads we have a few observations to offer.

FROM THE TIMES OF THE ANCIENTS TO THE INTRODUCTION OF THE FIRST FEASIBLE STEAM ENGINE.

The ancients appear to have had very vague notions of the nature of steam. They believed in the existence of only four elements—fire, air, earth, and water; and thought that water was turned into air when dissipated by evaporation. Thus Plato says, "That which we now call water becomes as a stone, or solid, but being melted and diffused becomes gas or air;" and it was the prevalent notion of his time, and of many subsequent ages, that water is turned into air by heat. In consequence of this misconception, it is often difficult to understand, in the description of ancient pneumatic contrivances, whether steam or air was the moving power, and we have indeed generally to form our conclusion on this head from the nature of the arrangement. We have, however, very clear evidence that both steam, and air expanded by heat, were often used by the ancients as motive powers, and some of the expedients employed for that purpose are of considerable elegance. In a work which has been often referred to, entitled *Spiritalia seu Pneumatica*, written by Hero, a philosopher of Alexandria, about 130 years before the Christian era, a variety of devices are set forth for elevating liquids, and obtaining rotatory motion by means of air and steam, of which we shall only enumerate those in which it is beyond doubt steam was the agent. The first of these is a method of causing wine to flow from the hands of effigies set beside an altar, after the fire upon the altar has been lighted. A steam-tight vessel or vase, containing wine, is placed within each effigy, and the altar is made hollow, and is partly filled with water, bent pipes being conducted from the space above the water in the altar to the spaces above the wine in the vases, and other tubes again being led from beneath the level of the wine in the vases to the hands of the effigies. When, therefore, says Hero, you are about to sacrifice, you must pour into the tubes a few drops, lest they should be injured by heat, and attend to every joint, lest it leak; and so the heat of the fire mingling with the water will pass in an aerial state through these tubes to the vases, and pressing on the wine make it pass through the bent syphons, until, as it flows from the hands of the living creatures, they will appear to sacrifice as the altar continues to burn.

The instrument for the production of rotatory motion is one of great ingenuity, and has all the qualities of a true and efficient steam engine, except its size. This instrument is called the Æolipile, and is identical in all its material features with the engines lately constructed by Avery in America, and Ruthven of Edinburgh, in this country. These engines are more expensive in steam than ordinary engines, and travel at an inconvenient speed; but in other respects they are quite as effectual, and their construction is extremely simple and inexpensive. The substance of Hero's recipe for the construction of an Æolipile is this. Let a boiler be set on the fire, and nearly filled with water, and let its mouth be closed by a cover which is pierced by a bent tube, whose extremity fits exactly into a hollow sphere. But at the opposite end of the diameter (of the sphere) let there be an iron axis supported from the top of the cover, and let the sphere have two bent pipes at the ends of a diameter of the sphere, perforated therewith, and bent round in opposite directions; and let the bends make right angles, and be in the plane perpendicular to the axis. Then it will follow that the boiler being heated, the vapour passing through the tubes into the sphere will rush out through the reversed pipes, and whirl the sphere round on its axis.

Hero specifies another modification of this instrument for giving motion to automaton figures, so as to induce the idea of supernatural intervention among the superstitious multitude by whom the heathen temples were frequented; but here heated air, instead of steam, is made the *primum mobile*, in order that the inciting power may be invisible. There is no doubt that pneumatical contrivances were extensively employed by the priests in ancient times for deluding the people, and it is easy to conceive that such treatises as that of Hero, which discovered the nature of those pious frauds, must have been the occasion, at the time, of infinite scandal. The celebrated statue of Memnon, which uttered sounds every morning at sunrise, was, no doubt, indebted to some such artifice as one of those described by Hero for its mysterious power. Very few of the devices he mentions are of his own invention, but most of them existed for ages before his time, although the knowledge of their structure and mode of operation appears to have been confined chiefly to the priests.

On the revival of classical learning throughout Gothic Europe the work of Hero attracted earnest attention, and several translations of it were made which afforded an early exercise to the infant art of printing. A knowledge of the expedients of the ancient mechanicians was thus widely diffused, and it was probably one of them that was reproduced in Spain in 1543 by Blasco de Garay, a sea-captain, for the propulsion of vessels. This contrivance, whatever may have been its real nature, appears to have been very effectual. Commissioners were appointed by the Emperor Charles V. to test the invention at Barcelona on the 17th of June 1543, and the result was that a ship of 200 tons burden was propelled by the machine at the rate of three miles an hour. Nothing further is known of the invention than that the vessel was propelled by paddle wheels, and that the moving force was derived from a boiler containing water, which, it was said, was liable to explode. It appears unaccountable that after the successful result realised by Garay, no further step should have been taken respecting his plan. He was rewarded by the Emperor, and promoted into a higher rank, but his ingenuity does not appear to have been ever turned to any useful account, and his scheme was never introduced into practice.

The various works on mechanics, published about the close of the sixteenth century, are full of expedients for the elevation of water similar to those of Hero, but much less refined; and Baptista Porta, in his book on Pneumatics, published at Naples in 1601, incidentally makes mention of the following contrivance, not indeed as any discovery of his own, but merely as an arrangement of convenience, in an experiment for ascertaining the relative bulks of water and steam. "Construct a box of glass or tin, having a hole at the bottom through which is introduced the neck of a flask, containing one or two ounces of water, and let the neck of the flask be so luted to the bottom of the box that there be no leakage. Near the bottom of the box let a pipe ascend, but at such a distance from the bottom as to permit the water to get out, which pipe passing through the cover is to rise a short distance above it. The box is to be filled with water by an aperture which is afterwards to be closed up, steam tight. This being done, place the flask upon the fire, and as it becomes slowly heated, the water being gradually dissolved into air will press upon the water in the box, and acting forcibly against the water which issues through the pipe, will not escape: and if we continue the heat, the whole of the water subjected to it will be evaporated, and during such evaporation the air will constantly press upon the water in the box, and the water will constantly spring from it." A similar arrangement is mentioned in a work by Solomon de Caus, a native of Normandy, or at all events a Frenchman; not for the philosophical purpose mentioned by Porta, but merely as an illustration that water might be raised above its level by fire, a truth known from the remotest antiquity. The work of De Caus, to which we have referred, is entitled *Les Raisons des Forces Mouvantes avec diverses Machines tant utiles que plaisantes*, Paris, 1623. This work is dated Heidelberg, 1615, and the first edition appears to have been published at Frankfort: it contains the following among several other theorems of equal insignificance:—"Take a ball of copper well soldered at every part; it must have a vent-hole to put in the water, and also a tube which is soldered to the top of the ball, the end of which approaches near to the bottom of the ball without touching it. After filling this ball with water through the vent-hole, stop it close and put it on the fire; then the heat striking against the ball will cause all the water to pass through the tube." De Caus also mentions a scheme of a solar fountain, but it, as well as the preceding, are merely clumsy imitations of some of the contrivances described by Hero. He gives the following illustration of the great force of steam:—"Take a ball of copper of one or two feet diameter, and one inch thick, which being filled with water by a small hole subsequently stopped by a peg, so that neither air nor water can escape, it is certain that if the said ball be put over a great fire so that it may become very hot, it will cause so violent a compression, that the ball will be shattered in pieces." The great force of steam, however, was very well known to the ancients, who even went the length of ascribing earthquakes to pent up vapours, generated by subterranean heat; and for ages the lime burners of Italy had been obliged to be careful of introducing hollow limestones into their kilns, as the water within them, when converted by the heat into steam, caused dangerous explosions. M. Arago, however, tells us that the ideas of the ancients respecting the force of steam had never reached any thing like the numerical appreciation realised by such experiments as those of De Caus. We confess that we are at a loss to understand wherein this numerical appreciation can consist, for although De Caus or Rivault may have ascertained that steam will burst a certain ball or bomb, they never ascertained what sort of ball or bomb steam will *not* burst, so that they did not establish any limit to the power of steam, but only showed that it is capable of very powerful effects. This, however, was known long previously; and in attributing to the force of pent up steam even such stupendous commotions as earthquakes—the upraising of continents and rending asunder of mountains—the ancients must have had at least quite as magnificent ideas of the force of that mighty agent as is to be afforded by the bursting of a ball or bomb, and we cannot perceive in what way an experiment establishes any thing which only proves that the power of an agent is adequate to the production of effects far more paltry than are known to be within the range of its capacity.

A contrivance for obtaining a rotatory motion from steam is described by Giovanni Branca, in a work published at Rome in 1629, entitled *Le Machine; volume nuovo et di multo artificio da fare effetti maravigliosi* *si tanto spiritali quanto di animale operatione.* This contrivance consists of a wheel furnished with boards set round its periphery, after the manner of an undershot water wheel, against which a jet of steam proceeding from a boiler is made to impinge, thereby forcing the wheel into revolution. An engine on this plan would necessarily be very ineffectual, and would indeed be greatly inferior to the Æolipile of Hero, for although it is undoubtedly the fact that the power of steam issuing from an orifice is expended in giving velocity to its own particles, and ought therefore, theoretically speaking, to be again surrendered by those particles during impact, yet this result cannot be realised in practice, and the great velocity at which the wheel requires to travel, makes the scheme perilous and impossible. Mr. Pilbrow, however, has during the past year revived this species of engine, and has taken out a patent for the particular arrangement he proposes. His engine is described and delineated in the first volume of THE ARTIZAN, and the causes are there pointed out, with considerable fulness of detail, which must prohibit its success.

The whole of the contrivances we have hitherto enumerated are mere mechanical toys, and although not incapable of useful applications, they appear only to have been employed to excite the wonder of the ignorant, and were never used for any serious purpose. To this judgment indeed the machinery of Blasco de Garay is an exception, for in that case, if the reports which have reached us may be relied upon, a useful result was undoubtedly realised. Yet this result contributed nothing to the success subsequently reached, and is rather an episode in the history of steam improvement, than a link in the chain of progress. The trial of De Garay's machinery indeed was a mere experiment, a successful one it is true, but one nevertheless which was barren in its effects, for in a few years all recollection of the achievement had become obliterated, and the contrivance, whatever might be its merits, was certainly never reduced to successful practice. It appears extremely probable that the machinery employed by De Garay was merely the ancient Æolipile on a superior scale of magnitude, for the low state of the mechanical arts in his time, and the small mechanical refinement to be expected of a sea-captain, equally discourage the idea that he should have reached any very exquisite or difficult kind of mechanism. It is idle, however, to speculate on such a subject, and we must therefore rest content with the certainty that the scheme of this enterprising person was never brought into practice, and that up to the epoch at which we have now arrived no useful application of steam power to the purposes of life had been accomplished.

The next name on our list is the Marquis of Worcester, who in 1663 published a pamphlet addressed to King Charles II. and the English Parliament, entitled "A Century of the Names and Scantlings of the Marquis of Worcester's Inventions," with the view to obtain the aid of government for their prosecution. Among many ingenious and some fantastic and preposterous devices, we have the following fire water-work, "An admirable and most forcible way to drive up water by fire; not by drawing or sucking it upwards, for that must be as the philosopher calleth it 'infra sphæram activitatis,' which is but at such a distance, but this way hath no bounder if the vessel be strong enough; for I have taken a piece of whole cannon, whereof the end was burst, and filled it three quarters full of water, stopping and screwing up the open end, as also the touch-hole, and making a constant fire under it; within twenty-four hours it burst, and made a great crack, so that having a way to make my vessels so that they are strengthened by the force within them, and the one to fill after the other, I have seen the water run like a constant fountain stream, forty feet high. One vessel of water rarefied by fire driveth up forty of cold water, and a man that tends the work has but to turn two cocks that one vessel of water being consumed another begins to force and re-fill with cold water, and so successively; the fire being tended and kept constant, which the self-same person may likewise abundantly perform in the interim between the necessity of turning the said cocks."

This is the first feasible scheme for raising water by steam power that history records, and it is in that application that the modern steam engine had its origin. Previous projectors had in no way improved upon the expedients described by Hero, and indeed in by far the majority of cases the movement had been retrograde; but in the Marquis of Worcester's contrivance we have an engine of respectable efficacy applied to a weighty purpose, and from his time the progress onward has never been interrupted, but improvement has followed upon improvement, until the steam-engine has become what we now find it. It is idle to say that the Marquis of Worcester's project was only a reproduction of that of De Caus. The instrument of De Caus was a mere toy, not intended, and certainly not adapted for any purpose of practical utility, whereas the Marquis of Worcester enumerates many important practical uses, to which his engine might be applied, and many of them it certainly would have been perfectly competent to compass. In another part of his Century he says that his water work "is by many years' experience and labour so advantageously by me contrived, that a child's force bringeth up an hundred foot high, an incredible quantity of water, even two foot diameter, so naturally, that the work will not be heard into the next room, and with so great ease and geometrical symmetry, though it work day and night from one end of the year to the other, it will not require forty shillings' reparation to the whole engine, nor hinder one day's work, and not only with little charge to drain all sorts of mines, and furnish cities with water though never so high seated, as well as to keep them sweet, running through several streets, and so performing the work of scavengers, as well as furnishing the inhabitants with sufficient water for their private occasions."

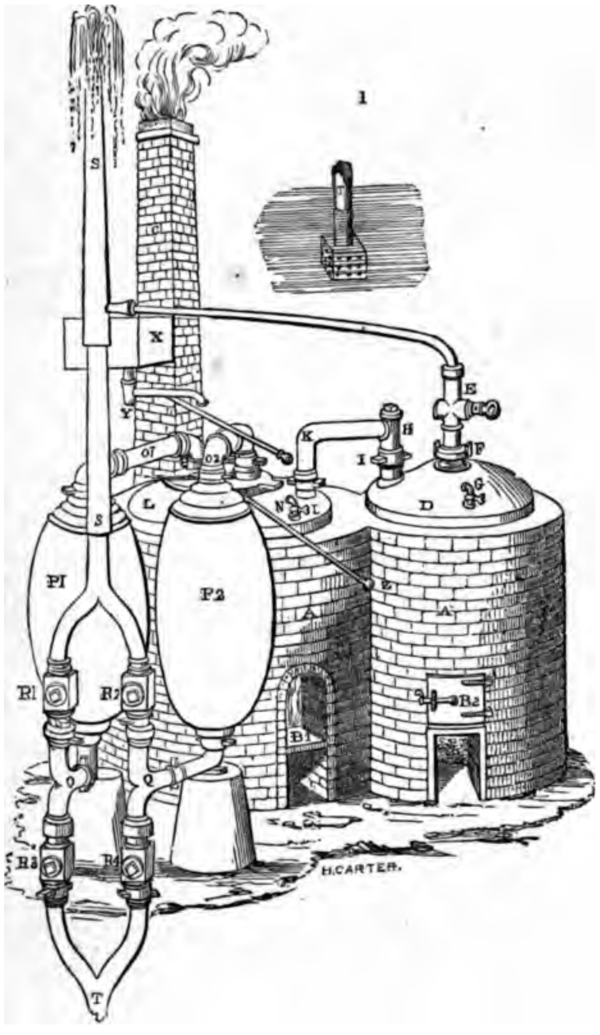
It appears very clear from these descriptions that the Marquis of Worcester not only had succeeded in making a powerful and effective engine, but had arrived at a very just conception of the important ends such a machine may be made to fulfil. None of the contrivances before his time were provided with means to make their action continuous, and the instrument of De Caus, so far from being adapted to raise water from a mine, or for the supply of towns, had merely the power of emptying itself of the *boiling water* with which it was filled. Indeed, it appears undeniable that the Marquis of Worcester was the first person, so far as our present knowledge extends, by whom "a water-commanding engine" of any power or utility was constructed, and he seems to have brought his contrivance to nearly all the perfection of which that species of engine is susceptible. There is no evidence that he made use of the atmospheric pressure as an aid to the final effect, but he seems perfectly conscious of the applicability of that agency, and indeed speaks as if such an application was very well understood in his time. We are not aware that there is any drawing extant of this machine; and the various hypothetical delineations of it that we have seen err, we think, in representing it as provided with only one boiler, for there could not in this kind of engine have been any feed-pump, and in the absence of that instrument two boilers must have been indispensable to make the action of the engine continuous. Besides the description says, that "one vessel of water being consumed another begins to force, and refill with cold water," which we take to mean that when the water of one boiler was evaporated it was filled up with cold water, and the other was in the meanwhile put into operation; the water in the boiler last filled having again become hot before that in the other was exhausted. One of these engines appears to have been set up to draw water out of the Thames at Vauxhall, and is thus spoken of by Cosmo de Medici, who inspected it in 1653. "It raises water more than 40 geometrical feet by the power of one man only, and in a very short space of time will draw up four vessels of water through a tube or channel not more than a span in width, on which account it is considered to be of greater service to the public than the other machine near Somerset House," which last was one driven by two horses. We should be disposed to infer from this account, that the principle of the atmospheric pressure was employed in this engine, for it is difficult to see by what power, other than suction, the necessary rapidity of motion could be given to the water in the pipe leading from the river to the engine, and which would appear to be smaller than the pipes applied in other cases.

We have now, then, brought the history of the steam engine down to the point at which its application to purposes of utility begins, and we believe most of our readers will concur with us in the opinion that the Marquis of Worcester's "water-commanding engine" was the first machine moved by fire of efficacy and permanence. To it, indeed, the pedigree of the modern steam engine is easily traceable, while between the epochs of Lord Worcester and of Hero nothing appears to have been contrived of novelty or merit in this department of ingenuity. We are not disposed, however, to attach any great merit even to Lord Worcester's contrivance, for it is deducible, without any great stretch of the imagination, from the schemes of Hero; and indeed there is very little doubt that the ancients would have realised a very effectual steam engine if they only had possessed mines that required to be drained, and coal to bestow on such a purpose. It is to the force of circumstances chiefly that the superior proficiency of the present age in such devices is to be ascribed; and we hold it vicious in principle to confound this impelling power with the ingenuity appertaining to particular inventors, and which nature dispenses with wonderful uniformity to all generations.

FROM THE INTRODUCTION OF THE FIRST USEFUL STEAM ENGINE TO THE APPLICATION OF THE PRINCIPLE OF A VACUUM.

We have already hinted our belief that the method of raising water by the action of the vacuum, or to speak more properly, by the atmospheric pressure, was not unknown to the Marquis of Worcester, and that in one of his engines erected at Vauxhall that agency was probably employed. We have no proof, however, that such was the case; and in the description of his engine in the "Century of Inventions," he certainly disclaims the use of a vacuum, at least as a chief agent. In the engine of Captain Savery, however, of which we must now say something, the plan of a vacuum is introduced with much effect, and instead of the water in his engine being forced up all the way by steam pressure, the receivers, or forcing vessels, are situated thirty feet above the level of the water, to which height the water is drawn by the vacuum created within them. As the principle of the atmospheric pressure is one which bears much upon this inquiry, it may be worth while to say a few words respecting it.

It was maintained by the greater number of the ancient philosophers that the existence of a vacuum was impossible, and was abhorrent to nature. Galileo was the first to suspect that the horror attributed to nature was imaginary, or was at least confined within limits of no very wide range, for on the application of a pump to a very deep well sunk by the Grand Duke of Tuscany at Florence, it was found that the water would not rise more than thirty-two feet, leaving the upper part of the pipe empty, from which Galileo inferred that nature's horror of a vacuum did not extend beyond the antipathy of thirty-two feet of water. The speculations of Galileo were prosecuted after his death by his pupil Torricelli, who, in 1643, discovered that the effort of any fluid open to the atmosphere to enter a vacuous space is owing to the pressure of the air upon bodies on the earth's surface. This discovery gave a great impulse to mechanical ingenuity, and many schemes were contrived to make this new agent available as a motive power; but the first of these projects that appears to have been of any avail was the fire engine of Captain Thomas Savery, who produced a vacuum by condensing steam in close vessels, and then applied the vacuum so obtained to the elevation of water. Savery, however, also made use of the elastic force of the steam after the manner proposed by the Marquis of Worcester; but he made the pressure of the atmosphere carry the water up the first stage, which the Marquis of Worcester does not appear to have done, although there must have been a vacuum created in his receivers as effectually as in those of Savery, occasioned by the condensation of the steam on the entrance of the cold water. Savery obtained a patent from William III. "for raising water, and occasioning motion to all sorts of mill-work by the impellent force of fire" in 1698; and for several years thereafter he appears to have been actively engaged in getting his engine introduced into practice. In 1702 he published a small work, called the "Miner's Friend," in which he gives the following account of the structure of his engine, and of the mode of its operation:—



SAVERY'S FIRE ENGINE.

"AA the furnaces which contain the boilers; B 1, B 2 the two fire-places; C the funnel, or chimney, which is common to both furnaces. In these two furnaces are placed two vessels of copper, which I call boilers, the one large, as L, the other small, as D; D the small boiler contained in the furnace, which is heated by the fire at B 2; E the pipe and cock to admit cold water into the small boiler to fill it; F the screw that covers and confines the cock E to the top of the small boiler; G a small gauge cock at the top of a pipe, going within eight inches of the bottom of the small boiler; H a larger pipe, which goes the same depth into the small boiler; I a clack or valve at the top of the pipe H (opening upwards); K a pipe going from the box above the said clack or valve, in the great boiler, and passing about an inch into it; LL the great boiler contained in the other furnace, which is heated by the fire at B 1; M, the screw with the regulator, which is moved by the handle Z, and opens or shuts the apertures at which the steam passes out of the great boiler into the steam-pipes OO; N a small gauge cock at the top of a pipe which goes half way down into the great boiler; O 1, O 2, steam-pipes, one end of each screwed to the regulator, the other ends to the receivers PP, to convey the steam from the great boiler into those receivers; P 1, P 2, copper vessels called receivers, which are to receive the water which is to be raised; Q screw joints, by which the branches of the water-pipes are connected with the lower parts of the receivers; R 1, 2, 3, and 4, valves or clacks of brass in the water-pipes, two above the branches Q, and two below them; they allow the water to pass upwards through the pipes, but prevent its descent; there are screw plugs to take out on occasion, to get at the valves R; S the forcing-pipe which conveys the water upwards to its place of delivery, when it is forced out from the receivers by the impellent steam; T the sucking-pipe, which conveys the water up from the bottom of the pit, to fill the receivers by suction; V a square frame of wood, or a box, with holes round its bottom in the water, to enclose the lower end of the sucking-pipe, to keep away dirt and obstructions; X a cistern with a buoy-cock coming from the force-pipe, so as it shall always be kept filled with cold water; Y Y a cock and pipe coming from the bottom of the said cistern, with a spout to let the cold water run down on the outside of either of the receivers P P; Z the handle of the regulator, to move it by, either open or shut, so as to let the steam out of the great boiler into either of the receivers.

The Manner of working the Engine.

"The first thing is to fix the two boilers of the engine in a good double furnace, so contrived that the flame of the fire may circulate round, and encompass the boilers to the best advantage, as you do coppers for brewing. Before you make any fire, unscrew the two small gauge-pipes, and cocks, G and N, belonging to the two boilers, and at the holes, fill the great boiler L two-thirds full of water, and the small boiler D quite full; then screw in the said pipes again as fast and tight as possible, and light the fire under the large boiler at B 1, to make the water therein boil, and the steam of it being quite confined must become wonderfully compressed, and therefore will, on the opening of a way for it to issue out (which is done by pushing the handle Z of the regulator as far as it will go from you), rush with a great force through the steam pipe O 1, into the receiver P 1, driving out all the air before it, and forcing it up through the clack R 1, into the force-pipe, as you will perceive by the noise and rattling of that clack; and, when all the air is thus driven out, the receiver P 1 will be very much heated by the steam. When you find it is thoroughly emptied, and is grown very hot, as you may both see and feel, then pull the handle Z of the regulator towards you, by which means you will stop the steam pipe O 1, so that no more steam can come into the receiver P 1, but you will open a way for it to pass through the other steam pipe O 2, and by that means fill the other receiver P 2 with the hot steam, until that vessel has discharged its air through the clack R 2 up the force pipe, as the other vessel did before.

"While this is doing, let some cold water be poured on the first-mentioned receiver P 1, from the spout Y, by which means the steam in it being cooled and condensed, and contracted into a very little room, a vacuum or emptiness is created, and consequently the steam pressing but very little (if at all) on the clack R 3 at the bottom of the receiver P 1, there is nothing there to counterbalance the pressure of the atmosphere on the surface of the water at the lower part V of the sucking-pipe T, wherefore the water will be pressed up, and ascend into and fill the receiver P 1, by what is commonly called suction: the water as it rises lifts up the clack or valve R 3, which afterwards falling down again and shutting close, hinders the descent of the water that way.

"The receiver P 2 being by this time emptied of its air, push the handle of the regulator from you again, and the force of the steam coming from the great boiler will be again admitted through Q 1, and will act upon the surface of the water contained in the receiver P 1; which surface only being heated by the steam, it does not condense it, but the steam gravitates or presses with an elastic quality like air, and still increasing its elasticity or spring until it counterpoises, or rather exceeds the weight of the column of water in the receiver and pipe S, which it will then necessarily drive up through the passage Q R 1 into the force-pipe S. The steam takes up some time to recover its power, but it will at last discharge the water out at the top of the force-pipe S, as it is represented in fig. 3. After the same maner, though alternately, the receiver P 2 is filled with water by means of the suction, and then emptied by the impellent force of the steam, whereby a regular stream is kept continually running out at top of the force-pipe S, and so the water is raised very easily from the bottom of the mine, &c. to the place where it is designed to be discharged. I should add, that after the engine begins to work, and the water is risen into and hath filled the force-pipe S, then it also fills the little cistern X, and by that means supplies the spout or pipe Y Y, which I call the condensing pipe, and which by its handle can be turned sideways over either of the receivers, *and is then open*; by this spout cold water is conveyed down from the force-pipe to fall upon the outside of either of the receivers when thoroughly heated by the steam, in order to cool and condense the steam within, and make it suck (as it is usually called) the water out of the well up into that receiver.

“ It is easy for any one, that never saw the engine, after half an hour's experience, to keep a constant stream; for on the outside of the receiver you may see how the water goes out as well as if the receiver were transparent: for as far as the steam continues within the receiver, so far is that vessel dry without, and so very hot as scarce to endure the least touch of the hand; but as far as the water is withinside of the said vessel, it will be cold and wet on the outside where any water has fallen on it; which cold and moisture vanish as fast as the steam in its descent takes place of the water. But if you force all the water out of the receiver, the steam, or a small part thereof, will go through the clack R 1 or R 2, and will rattle that clack so as to give notice to move the handle of the regulator, and then the steam begins to force out the water from the other receiver P, without the least alteration of the stream, only sometimes the stream will be rather stronger than before, if you pull the handle before any considerable quantity of steam be got up the clack R: but it is much better to let none of that steam go off, for that is but losing so much strength, and it is easily prevented by pulling the regulator some little time before that receiver which is forcing is quite emptied.

“ This being done, turn the cock, or condensing pipe Y of the cistern X, over the empty receiver, so that the cold water proceeding from X may run down through Y, which is never opened but when turned over one of the receivers, but when it stands between them is tight and stanch. This cold water falling on the outside of the receiver, by its coolness causes that steam which had such great force just before, to condense and become an empty space, so that the receiver is immediately refilled by the external pressure of the atmosphere, or what is vulgarly called suction, whilst the other receiver is emptying by the impellent force of the steam, which being done, you push the handle of the regulator from you, and thus throw the force into the other receiver, pulling the condensing pipe over the receiver P 2, causing the steam in that vessel to condense, so that it fills while the other empties—the labour of turning these two parts of the engine, viz. the regulator and condensing water-cock, and tending the fire, being no more than what a boy's strength can perform for a day together, and is as easily learned as their driving of a horse in a tub-gin. Yet after all, I would have men employed in working of the engine, and those too the most apprehensive, supposing them more careful than boys: the difference of this charge is not to be mentioned when we consider the vast profit which those who use this engine will reap by it.

“ The ingenuous reader will here probably object, that the steam being the cause of this motion and force, and that as steam is but water rarefied, the boiler L must in some certain time be emptied, so as the work of the engine must stop to replenish the boiler, or endanger the burning out or melting the bottom of the boiler. To answer which, please to observe the use of the small boiler D; it is supplied with water from the force-pipe by a small pipe and cock E; when it is thought fit by the person tending the engine to replenish the great boiler (which requires about an hour and a half or two hours' time to the sinking one foot of water), he turns the cock E, so that there can be no communication between the force pipe S, and the small boiler D, and putting in a little fire under the small boiler at B 2 the water will there grow presently hot, and when it boils, its own steam, which hath no vent out, will gain more strength than the steam in the great boiler. For the force of the great boiler being perpetually spending and going out, and the other confined and increasing, it is not long before the force in the small boiler exceeds that in the great one; so that the water in the small boiler being depressed by its own steam pressing on its surface, will force the water up the pipe H, through K, into the great boiler L; and so long will it run till the surface of the water in the small boiler D gets to be as low as the bottom of the pipe H, and then the steam and water will run together, and by its noise and rattling of the clack I, will give sufficient assurance to him that works the engine that the small boiler hath emptied and discharged itself into the greater one L, and carried in as much water as is then necessary; after which, by turning the cock E again, you may let fresh cold water out of the force-pipe S into the lesser boiler D, as before, and thus there will be a constant motion and a continual supply of the engine, without fear of decay or disorder. And inasmuch as from the top of the small boiler D to the bottom of its pipe H (which is within eight inches of the bottom of the boiler) there is contained about as much water as will replenish the great boiler L one foot, so you may be certain it is replenished one foot of course.

“ Also, to know when the great boiler wants replenishing or not, you need only turn the gauge-cock N, and if water come out there is no need to replenish it, but if steam only come, you may conclude there is want of water; and the like will the cock G do in reference to the small boiler D, showing when it is necessary to supply that with fresh water from S, so that in working the engine there is very little skill or labour required; it is only to be injured by either a stupid or wilful neglect.

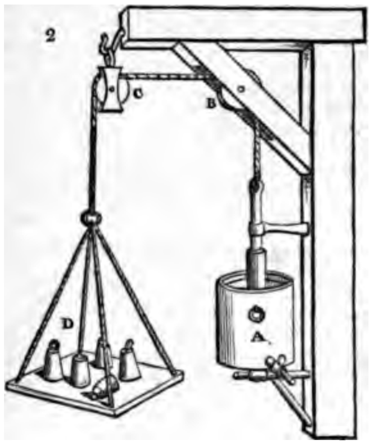
“ And if a master is suspicious of the design of a servant to do mischief, it is easily discovered by those gauge-pipes; for if he come when the engine is at work, and find the surface of the water in the great boiler L below the bottom of the gauge-pipe N, or the water in the small boiler D below the bottom of the gauge-pipe G, such a servant deserves correction, though three hours after that, the working on, would not damage or exhaust the boilers. In a word, the clacks being, in all water-works, always found the better the longer they are used, and all the moving parts of our engine being of like nature, the furnace being made of Sturbridge or Windsor brick or fire-stone, I do not see it possible for the engine to decay in many years; for the clacks, buckets, and mitre-pipes, regulator and cocks, are all brass; and the vessels made of the best hammered copper, of sufficient thickness to sustain the force of the working of the engine. In short, the engine is so naturally adapted to perform what is required, that even those of the most ordinary and meanest capacity may work it for some years without any injury.”

A good many of these engines appear to have been constructed and set to work. They were not employed, however, in any case in which water had to be lifted from a great depth, as the great pressure of steam requisite to overcome the gravity of a high column of water was reckoned inconvenient and dangerous in those days of fragile boilers and imperfect workmanship. These disadvantages appear to have been the chief cause of the relinquishment of Savery's engine in favour of that of Newcomen; for in the early career of Newcomen's contrivance the useful effect under certain circumstances was inferior to that of the engine it superseded, and the first expense was greater: but then Newcomen's plan made the column of water that could be lifted independent of the pressure of the steam, an increase in the height of the column only requiring an increase in the diameter of the cylinder. The details of Savery's contrivance are extremely judicious, and the scheme altogether speaks very favourably of his ingenuity and perseverance. It has been a matter of controversy whether he invented the engine altogether himself, or borrowed the idea from the Marquis of Worcester, and merely matured the plan of that noble mechanic. Desaguliers retails an idle story of Savery buying up the Marquis of Worcester's book in Paternoster Row and destroying it, so that the priority of the Marquis might remain unknown; but we give very little credit to the tale. There were probably at the time some of the Marquis's engines in being, which would be a much more conclusive testimony than any book could be, and at least there must have been many persons then living who recollected the engine set up by the Marquis at Vauxhall. Besides, the very act of buying up a book which had been many years in circulation, or rather of attempting to buy it up, would be the surest way to attract attention towards it, and thus produce the very disclosure it was Savery's imputed object to avert. We think it likely enough that Savery may have invented this engine entirely himself, without knowing anything of what the Marquis of Worcester had done forty years before, although in the pursuit of the subject he must of course have become acquainted with the achievements of his predecessor. The same wants generate so naturally the same expedients for their relief, that simultaneous discoveries and inventions become inevitable, and identical projects start up at different epochs without imitation, under the force of similar circumstances. The ingenuity, too, displayed by Savery in the details of his engine encourages the idea that it may have been altogether of his own contrivance, for he does not appear to have been unequal to such a performance, which indeed it did not require any very brilliant genius to accomplish. But whatever conclusion may be come to upon this head, we are at least certain that it was Savery who first introduced the fire-engine into extended use; and he prosecuted his undertaking with great assiduity and success; though, as he says, he “ was obliged to encounter the oddest and almost insuperable difficulties,” and at a great expenditure of energy and means. The merit of this achievement is in our apprehension much greater than that of the mere invention of the machine; for such a work is one of equal difficulty, and of infinite toil and discouragement, and is little lightened by the bright dreams of fancy or the consolations of applause.

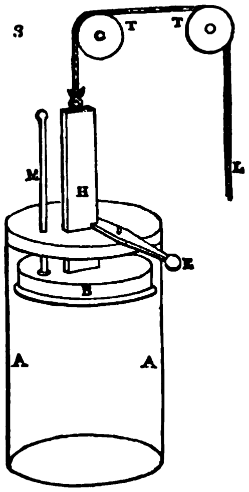
FROM THE APPLICATION OF THE PRINCIPLE OF ATMOSPHERIC PRESSURE TO THE INTRODUCTION OF THE CYLINDER.

About seven years after the discovery of the pressure of the atmosphere by Torricelli, Otto Guericke, a magistrate of Magdeburgh, without any knowledge of what Torricelli had done, succeeded in obtaining a vacuum in a cask by means of an air pump, and contrived a great variety of ingenious pneumatic apparatus; some for raising water in a pipe by means of an exhausted receiver screwed on the top, and others for lifting a great weight by means of a cylinder fitted with a piston, beneath which was a vacuum, while the atmosphere pressed on its superior surface. The nature of the arrangement he adopted in this latter case will be at once apprehended by a reference to the annexed figure, where A is a cylinder fitted with a piston, to the shank of which a rope is attached, passing over the pullies B and C with a scale D hung at its extremity loaded heavily with weights. A small pump was screwed into the lower part of the cylinder, by means of which the cylinder was exhausted, and the piston descending raised the weights.

We have in these ingenious devices the same mechanical arrangements as those afterwards employed by Savery and Papin in their projects; and indeed the only material difference between the cylinder apparatus here represented and the atmospheric steam engine is that in the one case the vacuum is produced by means of a pump, and in the other by the condensation of steam. It is in the production of a vacuum, therefore, by the



agency of steam, that any merit in the contrivance of the atmospheric steam engine must be held to consist, for the efficacy of a vacuum when produced in raising heavy weights, or in the production of other powerful mechanical effects, could not fail after Guericke's experiments to be obvious to every one. Savery says he discovered the efficacy of steam in the production of a vacuum by plunging the neck of a flask he had accidentally thrown upon the fire with a little wine in it into a basin of water, when the steam raised from the wine was condensed, and the water rose into the flask and filled; but Desaguliers throws discredit upon this account, by saying that in such an experiment the flask would have been forced from the hand of the operator by the impulse of the entrant water, a circumstance of which Savery makes no mention. Mr. Scott Russell, however, says that he has tried the experiment many times, and that the catastrophe indicated by Desaguliers is conditional upon the diameter of the neck of the flask, the temperature of the water, and other circumstances, so that we really see very little reason to doubt the truth of Savery's statement. The date of this experiment of Savery's does not very clearly appear. It must of course have been antecedent to his patent of 1698; but whether it was before the year 1690, at which time Papin published a scheme for creating a vacuum in a cylinder by the condensation of steam, is uncertain. The question, however, is one of very little moment, for both of these projectors were long preceded in their discoveries; the method of producing a vacuum by steam agency having been known even before any idea had been formed of the atmospheric pressure. The manner of re-filling the Æolipile was to plunge it, while a jet of steam was issuing from it, into a vessel of water, whereby the steam within it was condensed, and the water was drawn with great rapidity through the small orifices through which the steam escaped, by means of the internal vacuum. In the Marquis of Worcester's engine, again, as, we believe, we have already indicated, a vacuum must have been formed by the condensation of the steam so soon as the cold water began to enter the receivers, though from what Cosmo de Medici tells us, we should be disposed to conclude that the power thus generated was wasted in drawing the water through contracted passages, rather than in raising it up to any considerable elevation. We believe, however, that both Savery and Papin re-discovered the means of producing a vacuum by the condensation of steam, or more properly perhaps saw, independently of their predecessors, and of each other, the feasibility of producing a convenient and effectual vacuum by this agency, for it is hardly conceivable that in the times of Newton, Hooke, and Boyle, the effect of the condensation of steam in producing a vacuum should not have been a matter of extended notoriety. In this, indeed, as in most other cases, a reference to the current intelligence of the time will show that even the most noted projectors advanced very little beyond it; and many a genius, with whose name the world has rung, will, when measured by this standard, collapse to the dimensions of a pigmy. Inventions sown in one age are ripened in another by the progress of events, but a multitude of agencies are necessary to the final effect, and of these the most important is Time. Individual projectors are merely like bubbles dancing upon the waves of that majestic stream: though higher than the other liquid particles around them, yet their altitude is not to be measured from the position of the lowest surface, and they are not the cause of the total exaltation.



As we have several times mentioned the name of Papin, we must, we suppose, say who he was. Denys Papin, then, was born at Blois, in France, and was educated to the profession of medicine. Being a Protestant, he was driven from France by the revocation of the edict of Nantes, and settled in London, where he assisted Mr. Boyle in his experiments with the air-pump, and was elected a member of the Royal Society in 1680. During this period he invented the culinary utensil called Papin's digester, of which he published an account in 1682. In 1687 he was appointed professor of mathematics at Marburg, in Germany, and in 1690 he proposed a scheme in the *Acta Eruditorum* of Leipsic, for producing the vacuum required in Otto Guericke's cylinder arrangement, by the agency of steam. A A (*fig.* 3.) is a thin metal cylinder, fitted with a piston B, and a piston-rod H with a notch in its side, into which a latch, E, falls to prevent the descent of the piston until the latch is withdrawn. A rope, L, is fastened to the piston-rod, and passes over pullies T T, precisely as in Guericke's contrivance, and may be employed to raise weights in the descent of the piston. Water is introduced underneath the piston through the hole closed by the screwed rod M, and a fire is applied beneath the cylinder bottom, which raises the water into steam, and forces the piston up, the latch falling into the notch in the piston-rod so soon as the piston has risen sufficiently. The fire is now to be withdrawn from the cylinder bottom, and in a certain time the steam in the cylinder will become condensed, when the latch is to be drawn backwards, and the piston will be forced down by the pressure of the atmosphere. It requires little penetration to see that this scheme would be quite useless in practice; for the continual removals of the fire, the injurious effect of fire on the cylinder, and the absence of any expedient to facilitate refrigeration, are most effectual barriers to its successful application. Indeed, the project is greatly inferior in efficacy to the plan of the Marquis of Worcester, which was provided with a boiler, and which proved itself susceptible of a practical use. With Savery's engine, projected about the same time, the crude project of Papin is not to be put in comparison; and indeed Papin appears to have been so thoroughly convinced of the superiority of Savery's contrivance, that he gave up his own plan and adopted that of Savery. Papin, however, was a person of much ingenuity, but most of his schemes were visionary; and whatever might be his other merits, he certainly contributed nothing to the improvement of the steam engine, either by his performances or suggestions. He neither was the first to suggest the formation of a vacuum in a cylinder fitted with a piston, nor the first to discover the method of producing a vacuum by the agency of steam, and he certainly was not the person who first carried this combination to any result of moment or utility.

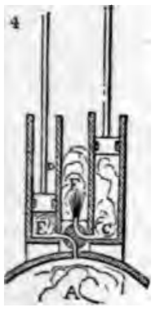
The first successful engine which operated by means of a cylinder and piston was contrived by Thomas Newcomen, an ironmonger of Dartmouth, and John Cawley, a glazier of the same place, about the year 1710. The object of the innovation appears to have been not so much to obtain a more effectual and economical engine than that of Savery, as to dispense with the necessity of employing steam of a very high elasticity where water had to be raised to a considerable height, and which, in those days, was the occasion of considerable inconvenience and danger. We think it very probable that Newcomen was acquainted with the project of Papin at the time he introduced his own engine into practice, as well as his relinquishment of it in favour of Savery's scheme, but this rather adds to Newcomen's merit than diminishes it, as it shows him to be no imitator of Papin, and to be in no wise influenced by his authority. It is to Newcomen, therefore, that we owe the cylinder steam engine, for Papin not only never projected any cylinder steam engine that was practicable, and never made one, but had gone back before Newcomen's time to Savery's scheme; and although Sir Samuel Morland, so far back as 1682, had contrived cylinders for raising water by steam power, yet we have no reason to believe that he put his plan in practice; and the outline he has left of it in his "Principles of the new Force of Fire" is too meagre to give any certain intimation of the nature of the contrivance, though the probability is that it more nearly resembled the Marquis of Worcester's engine than that of Newcomen. It does not appear, however, that Newcomen was himself conscious of the advantages of his own method of construction beyond that of the greater convenience of low pressure steam, and, indeed, his engine would have remained very little better than that of Savery, at least for moderate heights, but for the improvements effected by subsequent inventors. Of these improvements we must now give some account.

FROM THE APPLICATION OF THE CYLINDER TO THE DISCOVERY OF THE MODE OF CONDENSING BY JET, THE USE OF SELF-ACTING VALVES, AND THE COMPLETION OF THE IMPROVEMENTS OF SMEATON.

Newcomen's engine, as at first constructed by him, was provided with a casing around the cylinder for holding cold water, to accelerate the condensation of the steam, and the surface of the piston was covered with water to prevent the passage of air past it. The steam was admitted from the boiler by a slide valve or regulator, as in Savery's engine, which was moved by hand, and after the cylinder was filled with steam, water was introduced into the external casing, by which, in process of time, the steam was condensed, and the piston then made a stroke. This, however, it is evident, must have been very tedious work, and the engine indeed was very untractable until the method of condensing the steam by a jet of cold water was introduced, and the movement of the valves was effected by the engine. These improvements were the effect of accident: the mode of their development is thus related by Desaguliers:—"In the latter part of the year 1711 Newcomen and Cawley made proposals to drain the water of a colliery at Griff, in Warwickshire, where the proprietors employed 500 horses, at an expense of 900*l.* a year; but their invention not meeting with the reception they expected, in March following, through the acquaintance of Mr. Potter of Bromsgrove, in Worcestershire, they bargained to draw water for Mr. Back of Wolverhampton; where, after a great many laborious attempts, they did make the engine work: but not being either philosophers to understand the reason, or mathematicians enough to calculate the powers and proportions of the parts, they very luckily, by accident, found what they sought for.

"They were at a loss about the pumps, but being so near Birmingham, and having the assistance of so many admirable and ingenious workmen, they came about 1712, to the method of making the pump-valves, clacks, and buckets, whereas they had but an imperfect notion of them before. One thing is very remarkable: as they at first were working, they were surprised to see the engine go several strokes, and very quick together, when, after a search, they found a hole in the piston, which let the cold water in to condense the steam in the inside of the cylinder, whereas before they had always done it on the outside. They used before to work with a buoy to the cylinder, enclosed in a pipe, which buoy rose when the steam was strong and opened the injection, and made a stroke; thereby they were capable of only giving six, eight, or ten strokes in a minute, till a boy, named Humphrey Potter, in 1713, who attended the engine, added (what he called *scoggan*) a catch, that the beam always opened, and then it would go 15 or 16 strokes a minute. But this being perplexed with catches and strings, Mr. Henry Beighton, in an engine he had built at Newcastle-upon-Tyne, in 1718, took them all away but the beam itself, and supplied them in a much better manner."

The boilers of the engines made by Savery do not appear to have been provided with safety valves, nor do they appear to have required such an application, as the regulators were in all probability so constructed that the passages of both receivers could not be closed at the same time. About the year 1717, Desaguliers constructed an engine on Savery's plan, but with only one receiver, and, as the only passage through which the steam could find vent would sometimes in such an engine be closed, and might be so left by a careless attendant, it became necessary to apply a safety-valve to the boiler. This species of valve had been applied by Papin to his digester, and its application to the steam-engine had been suggested by him; but the expedient was superfluous so long as the pressure of the steam was balanced by a column of water, which would be overcome before any dangerous elasticity, could be attained.



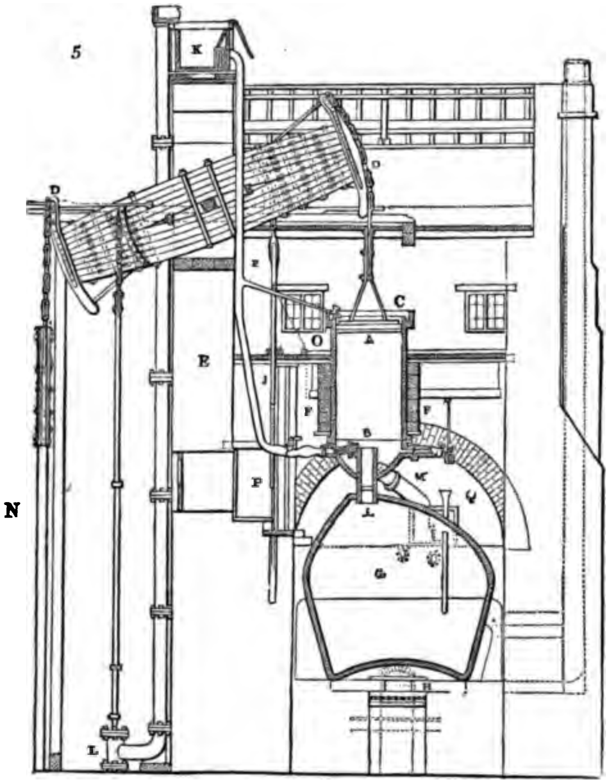
In 1720 a very elegant high pressure engine was contrived by Leupold, and described in his *Theatrum Machinarum*; the plan of which will at once be understood by reference to the annexed diagram, where A is the boiler, E and C the cylinders, F the waste steam proceeding from the four-way cock. In this engine, the four-way cock first occurs, and the scheme altogether is marked by a refined ingenuity not unworthy of Watt and his successors. The effect of the two cylinders placed in juxtaposition is identical with that of the double-acting engine; and the machine is altogether the simplest and most artistic that, up to this time, had been projected. The employment, however, of high pressure steam could not fail to be looked upon as very objectionable at a period when boilers were so rude and unsubstantial; and we suppose it was owing to this objection that the plan of working by high pressure steam did not, until very recently, come into practice. The domes of the boilers employed by Newcomen were generally of lead, the inferior portions being composed of copper; and it was not until many years after steam engines were applied to practical uses, that boilers composed altogether of iron plates rivetted together, were introduced, or that the art of making boilers had reached such perfeetion, that a high pressure might be put upon them with safety.

From the improvement of the valve gearing by Beighton, in 1718, very little alteration appears to have been made in the atmospheric engine until the time of Smeaton. Brindley, indeed, added the contrivance of a float in the boiler, to regulate the admission of the feed-water, and also proposed that the boiler should be constructed of wood or stone, furnished with an internal furnace and internal flues: but his attention was withdrawn from the steam-engine to other subjects, and very little real improvement resulted from his ingenuity. In 1767, Smeaton was employed to construct an engine by the New River Company, into which he resolved to introduce several alterations. Conceiving that a good deal of power was dissipated in the rapid reciprocation of the beam, and in giving a needless momentum to the water in the pumps, he determined to work the engine at a less velocity, to employ larger pumps, and to load the piston with 10½ lbs upon the inch instead of 7 lbs., as had been the usual practice. To carry into effect these intentions, the main centre was removed from the middle of the beam to a point nearer the end from which the pumps were hung, and the cylinder was made tall and of small diameter, by which peculiarity it was conceived the steam would be more readily condensed, and a less amount of injection water would suffice. "I thought myself," says Smeaton, "quite secure under those advantages; but how great was my surprise and mortification, to find that, instead of requiring less injection water than common, although the injection pump was calculated to afford as much injection water as usual, in proportion to the area of the cylinder, with a sufficient overplus to answer all imaginable wants, it was unable to support the engine with injection, and that two men were obliged to assist to raise the injection water quicker, by hand, to keep the engine in motion; at the same time that the cylinder was so cold, I could keep my hand upon any part of it, and bear it for a length of time in the hot-well. By good fortune, the engine performed the work it was appointed to do, as to the raising of water, but the coals by no means answered my calculation. The injection pump being enlarged, the engine was in a state for doing business, and I tried many smaller experiments, but without any good effect, till I altered the fulcrum of the beam so much, as reduced the load upon the piston from 10½ lbs. to 8¾ lbs. per inch. Under this load, though it shortened the stroke at the pump end, the engine went so much quicker as not only to raise more water, but consume less coals; took less injection water; the cylinder became hot, and the injection water came out at 180° of Fahrenheit; and the engine in every respect not only did its work better, but went more pleasantly. This at once convinced me that a considerable degree of condensation of the steam took place in entering the cylinder, and that I had lost more by this way, by the coldness of the cylinder, than I had gained by the increase of load. In short, this single alteration seemed to have unfettered the engine; but in what degree this condensation took place, under different circumstances of heat, and where to strike the medium, so as upon the whole to do best, was still unknown to me. But resolving, if possible, to make myself master of the subject, I immediately began to build a small fire engine at home, that I could easily convert into different shapes for experiments, and which engine was set to work in the winter of 1769."

This engine was set up at Austhorpe, and by its assistance Smeaton investigated the operation of the steam-engine after the same practical fashion that he had previously adopted in investigating the operation of water-wheels and windmills. The diameter of its cylinder was 9·9 inches, length of stroke 3 feet, number of strokes per minute 17½, and the load upon the piston 7·89 lbs. per square inch. This is not quite one-horse power, for $(9{\cdot}9)^2 = 77$ square inches × 7·89 = 607 lbs. and × by 52·5, the effective motion per minute = 31,867 lbs. raised one foot high per minute, or ÷ by 33,000 = ·966 HP. The consumption of coals per hour was 55 lbs.: a bushel, therefore, or 84 lbs. would suffice for 91·6 minutes, which is equivalent to 2·92 millions of pounds raised one foot high by a bushel of coals. The quantity of injection water required was found by measurement to be 95 cubic inches per stroke, and the quantity of water evaporated from the boiler was about 8·9 cubic inches per stroke, so that the quantity of water required for injection was 10·66 times greater than that requisite for the supply of the boiler, though this proportion would, of course, vary somewhat with the temperature of the atmosphere. This engine must have lost about half of its efficacy by condensation in the cylinder, for 8·9 cubic inches of water will make 8·9 cubic feet of steam to be consumed per stroke, which is about double the capacity of the cylinder and its waste spaces. A good deal of the heat thus lost, however, appears to be due to radiation from the surface of the cylinder, for not above two thirds of the whole heat is to be found in the hot well, the temperature of which was only 134° when the temperature of the injection water was 68° or 70°. The load on the piston was varied in the experiments by taking away or adding a length of pipe to the superior part of the pump barrel, and it was found that the load of 7·81 lbs. per square inch on the piston was the most beneficial one, both as regards the quantity of work done and the consumption of fuel. When the load was diminished to 6·6 lbs. the efficacy, or, in other words, the duty of the engine, estimated at 100, was reduced to 94, and, by diminishing the load to 5·5 lbs. the efficiency was reduced as low as 82, while by increasing the load from 7·81 to 8·8 lbs. the work done was only increased from 100 to 107, although the consumption of fuel proceeded in a much higher ratio, and by a further increase of the load to 9·1 lbs. the efficiency was reduced from 100 to 96, though at an increased expenditure of fuel. In diminishing the load below 7·81 lbs. to 6·6 lbs. the efficacy of a pound of coal was reduced from 100 to 94, and the further diminution to 5·5 lbs. reduced the efficacy of a pound of coal from 94 to 80, while the increments in the load reduced the efficacy of the fuel from 100 to 97 in the first case, and from 97 to 93 in the second. The relative efficacy of different kinds of coal was also tested in these experiments. Rubbly coal was found superior to slack in the proportion of 100 to 80. Coke was of about the same efficacy as slack, and 100 lbs. of coal were found to produce about 66 lbs. of coke. The Newcastle coal called Team Top was found more effectual than the Halton or common Yorkshire coal in the proportion of 120 to 100, and Cannel coal more effectual than Halton in the proportion of 133 to 100. Smeaton continued his experiments with this engine for four years, and recorded the results in a book of tables which he employed to regulate his future practice. In 1772 he was employed to construct an engine for Long Benton colliery near Newcastle, in which he embodied the several improvements his experiments had suggested. In all its main features this engine was identical with the previous constructions of Beighton, but it was distinguished by juster proportions and greater nicety of detail than had yet been realised, and the innovations thus introduced were found to be highly beneficial in practice. The engine at Long Benton Mr. Smeaton looked upon as his standard work, but his most magnificent performance in this way was the Chase Water engine erected in 1775 at one of the mines of Cornwall. Of these engines we must contrive to give a brief description.

The diameter of cylinder in the Long Benton engine was 52 inches; length of stroke 7 feet; load on the piston 7½ lbs. per square inch; number of strokes per minute 12; and $52^2 \times {\cdot}7854 \times 7\tfrac{1}{2} \times 84 \div 33{,}000 =$ about 40½ horse-power. The consumption of fuel was 8½ bushels of Newcastle coals per hour which at 84 lbs. per bushel is 17·63 lbs. per horse-power per hour, or 9·45 mil lions of pounds, raised one foot high by a bushel of coal. The evaporation of water by the boilers was 90 cubic feet per hour, by 8½ bushels, =10·58 cubic feet, evaporated by a bushel or 84 lbs., or 7·88 lbs. evaporated by each pound of coal. If the steam within the boiler be considered to be 1700 times less dense than water, which would be near the truth, then 2550 cubic feet of steam would be generated per minute; but of this not so much as one-half could be spent in producing a useful effect, for the space within the cylinder occupied by the motion of the piston would only be 103·25 cubic feet × 12 =1239 cubic feet per minute, which is not half of the steam generated. The residue, therefore, must have been lost by leakage and condensation, and by the space left between the piston and the bottom of the cylinder. This space would cause a loss of about 360 cubic feet per minute, leaving a loss of above 950 cubic feet per minute, to be accounted for by leakage and condensation, or indeed by condensation alone, as the leakage was inappreciable. The internal surface was 168 square feet, so that each foot of cylinder surface must have condensed about 5·66 cubic feet of steam per minute. There were three boilers, and they were so proportioned as to afford 3·5 square feet of furnace surface, 7·83 of flue surface, and ·867 feet of fire-grate per horse-power.

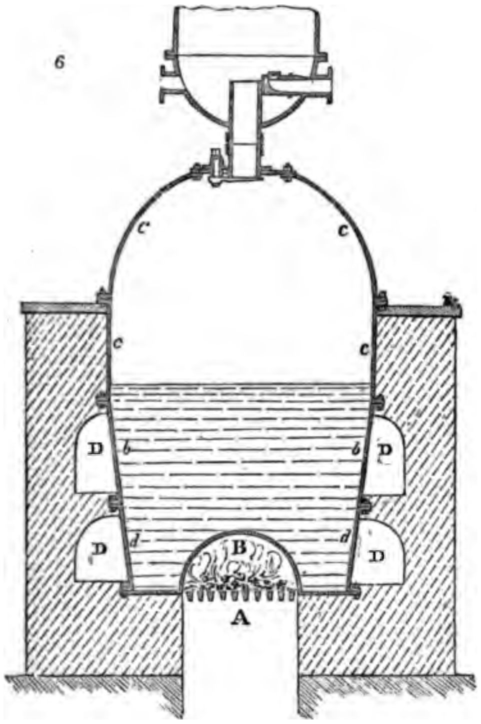
The structure and arrangement of the Chase Water engine were almost identical with those of the engine at Long Benton: it was, however, of greatly superior power. The cylinder of the Chase Water engine was 72 inches in diameter; length of stroke 9 feet; number of strokes per minute 9=81 feet of effective motion, and load upon the piston 7⅔ lbs. This gives a power of about 76½ horses for $72^2 \times \cdot7854 \times 81 \times 7\frac{1}{3} \div 33{,}000 = 76\frac{1}{2}$ HP. The configuration of these engines will be seen at once by a reference to the following wood-cut, where A B is the cylinder, C the piston made of iron and covered on the bottom with elm planking, secured with screw-bolts to the piston. Between this planking and the iron of the piston, tarred flannel is interposed to retard the transmission of heat, and thereby render the condensation within the cylinder less serious. D is the great lever, 27 feet 4 inches long, consisting of twenty pieces of fir, the four nearest the middle being 12 inches square, and the other sixteen being 6 inches by 12 inches. These pieces of timber are prevented from rubbing upon one another by means of oak keys, driven into mortices prepared for their reception, and are bolted together by 32 long iron bolts, 1 inch in diameter, passing through the whole depth of the lever. The axis of the lever, where it passes through the wood, is 30 inches wide by 5 inches thick. The bearings are 8½ inches in diameter, resting in brass bushes, let into blocks of wood built into the lever wall. Breadth between bearings 3½ feet; breadth of beam 2 feet; depth of beam at centre 74 inches; depth at extremities 60 inches. E is the lever wall; F F the beams which support the cylinder, or rather which keep it down, and which are retained in their places by the walls of the house; G is the boiler, H the furnace, I the steam pipe, J the injection pipe, terminating in a wooden jet piece jammed between the steam pipe and the side of the cylinder, the use of wood in this situation being to diminish the condensation by a non-conducting substance. K is the cistern for holding the injection water, and which is placed in an elevated situation to cause the more perfect dispersion of the injection water by the force with which it enters the cylinder. L is a pump for raising the injection water into the cistern. M is the eduction pipe, terminating in the hot well, and fitted with a valve at its inferior extremity, to prevent the regurgitation of the water. N pump rod of the pump of the mine; O a band or strap extending to the cataract; P P the plug rod, by which the valve gearing is wrought. The steam pipe is 12 inches in diameter, the eduction pipe 8 inches; and the two short necks for the injection cock and snifting valve 6 inches diameter. These are all cast in the same piece with the hemispherical bottom. The snifting valve consists of a short plug of boxwood driven tight into its seat, fitted with a circular flap valve applied to the end of the plug; over this a conical pipe is fixed with a cock at its extremity, so as to regulate the amount of the snift at pleasure. "The upright feed pipe, Q," says Smeaton, "is designed to answer the double purpose of a lower gauge cock and a safety pipe. Two or three small holes are to be pierced through it at the proper depth for a lower gauge cock, that is, at the lowest level which is proper for the water in the boiler, and three inches below these holes the pipe is to be pierced with a hole half an inch in diameter, and again at three inches lower the pipe must terminate altogether. By this means, if the water in the boiler sinks too low, the small holes in the feeding pipe will emit steam and give notice by a rattling noise; but if the water is suffered to subside still lower, the steam will blow out by the half inch hole, and the noise will produce a greater alarm; and when the water sinks so low as to be at intervals below the bottom of the pipe, the water and steam will issue in such a manner as to make a very great noise, and call the engine-man to his duty even if he have fallen asleep."



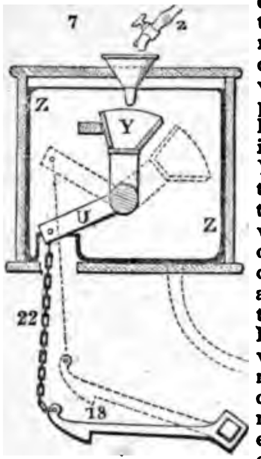
CHASE WATER ENGINE

Such then are the principal details of this celebrated engine; and we must now proceed to explain in a few words the manner in which the atmospheric engine operates. When the engine is at rest, the end of the lever from which the pump is hung will always proponderate, that end being purposely made heavier than the other, to overcome the friction and inertia of the lever, as it cannot be elevated by the force of the steam. The first step in starting the engine is to open the regulator or slide valve which interposes between the boiler and cylinder. The cylinder will of course immediately become charged with steam, but the steam will at first be very rapidly condensed by the cold metal, and will continue to condense until the cylinder has become nearly as hot as the steam itself. As soon as this takes place, the steam will open the snifting valve, and drive out the air with which the cylinder had been filled, and the sign of the thorough expulsion of the air is that the steam will then issue in a transparent, and not in a cloudy state. While the steam is thus issuing from the snifting valve the injection valve situated in the injection cistern at the top of the engine-house must be drawn open by the cord attached to it, and the handle which had been depressed to open the regulator must be raised. This will close the connection between the boiler and the cylinder, and will at the same time open the injection cock, and an instant vacuum being produced by the jet of cold water, the engine will make a stroke. The plug-rod in its descent strikes with a projection or tappet the handle which had just been raised, which shuts the injection cock and opens the regulator, and as the pressure of the steam is about equal to the pressure of the atmosphere, the piston ascends, being drawn up by the preponderance of weight at the other end of the lever. The plug-rod in its ascent, when near the end of the stroke, strikes the handle upwards by means of another peg or tappet, by which the steam passage is again closed, and the injection passage opened. The piston thus makes another stroke, and the same action is continued so long as the engine is kept supplied with steam and cold water. The hot water produced by the condensation of the steam flows out of the cylinder by the eduction pipe into the hot well, whence a part of it flows into the boiler to restore the quantity evaporated, and the remainder runs to waste. A small branch leading from the injection pipe distributes water over the upper surface of the piston to prevent the leakage of air, and any air that may find admission either in the steam or otherwise, and which, if suffered to accumulate in the cylinder, would destroy the action of the engine, is driven out every stroke by the snifting valve. A certain leakage of air, however is beneficial, as it diminishes greatly the condensation of the steam; for the air, being diffused equably among the steam, will accumulate against the sides of the cylinder as against a sieve, which is pervious to heat but not to air; and this film of air will prevent the access of the steam to the naked iron to suffer a destructive refrigeration. After a better quality of workmanship had been introduced by Smeaton, it was found that the engines were actually *too tight;* and an air-cock was therefore appended to give a regular admission to such a quantity of air as might be found beneficial.

Before Smeaton commenced his improvements in the steam engine, he ascertained with much care the performance of a number of the engines then in existence; and of 15 engines at Newcastle he found that the best raised about 7½ millions of pounds one foot high with a bushel of coals, and the worst only 3¼ millions. The engine he afterwards erected at Long Benton, and in which his improvements were fully carried out, raised, as we believe we have already stated, about 9½ millions; so that there was much less difference between the performance of the best of the common engines and Smeaton's engines than between the common engines themselves. The improvements introduced by Smeaton chiefly resolve themselves into greater care in the construction of the engines, and a better proportion and arrangement of the boiler, and involve neither the application of any new principle nor any great expenditure of ingenuity. Before Smeaton's time the manufacture of engines was in the hands of very ignorant mechanics who did not know the difference between power and force; and their perpetual aspiration was to make the piston exert a great force, without taking into account the velocity of movement necessary to make it operate effectively. It was very rarely the case that the engine was adequately supplied with steam: and when an engine was found incompetent to its work in consequence of this inadequacy, it was generally provided with a larger cylinder, which only aggravated the evil. Then the cylinders were very ill bored; and the condensation from the water lying on top of the piston, as well as from the water escaping past it, was very considerable; while, at the same time, the piston rarely travelled a sufficient distance in the cylinder, and a great deal of steam was lost every stroke by filling a useless vacuity. The boilers, besides being too small, were generally badly set, the bottom being too far from the fire; and the firing was badly conducted, the coals being piled in a heap in the middle of the grate instead of being spread evenly over it. The injection cistern was generally set too low, by which means the water was not adequately dispersed within the cylinder; and the valve gearing was for the most part so constructed that the regulator did not open fully, by which means the steam was throttled, and a heavy counterweight was necessary to suck the steam into the cylinder, which of course had afterwards to be raised at an expenditure of power. These faults Smeaton corrected: his plan of sheathing the under side of the piston with wood prevented much of the condensation by the water lying on top of it; and the use of more perfectly bored cylinders, which the establishment of the Carron iron works about this time enabled him to obtain, obviated the condensation from water trickling down the cylinder sides. The boilers he introduced were very effectual and satisfactory. The annexed diagram represents one of his favourite varieties of construction, called the haystack boiler, and is formed of cast iron. Three of these boilers, 10 feet in diameter and 16 feet 4 inches high, were constructed to supply an engine with a 66 inch cylinder and 8½ feet stroke, designed by Smeaton for pumping out the docks at Cronstadt in Russia. A is the ashpit; B the furnace; C C the hemispherical top of the boiler; *c c* a cylinder joined with flanges and screws to the top to give more steam room. *b b* and *d d* conical pieces joined to the cylindrical piece, and which, with the bottom, complete the boiler; D D are the flues. Where the water used for injection was of such a quality as would injure the boiler, as was the case with some kinds of water raised from mines, and there was no abundant supply of better water at hand, it was Smeaton's practice to collect a sufficiency of good water, to suffice for the feeding of the boiler, either by a rain cistern or otherwise; and he warmed this water, before sending it into the boiler, by transmitting it through a worm or cistern situated in the hot well. The movement of the engine, when the quantity of work to be done was irregular, was commonly regulated by a contrivance called the cataract, or, as it was termed by the miners, the Jack-in-the-box. This apparatus consists merely of a small cock, *z*, through which a drip of water is suffered to pass into the vessel, Y, situated within the box Z, and so poised upon a centre, in connection with the lever, U, that U will preponderate when Y is empty, but not when it is full. When Y becomes full, it will tilt over in the direction indicated by the dotted lines, raising the catch 18 by the chain 22, and by this act will empty itself of the water, and resume its original position. The water flows away out of the box, Z, which is lined with lead, after having performed its function in raising the catch; and the catch, when raised, releases a weight, which opens the injection valve, and the engine makes a stroke. The number of reciprocations, therefore, of the cataract determines the number of strokes made by the engine, so that the speed of the engine is thus regulated by the degree of opening given to the cock, *z*, and which is determined by the quantity of water to be drawn. The cataract is not a contrivance of Smeaton's, but was used in the Cornish engines before his time. A much better variety than that here figured is now employed, which will be described in its proper place.

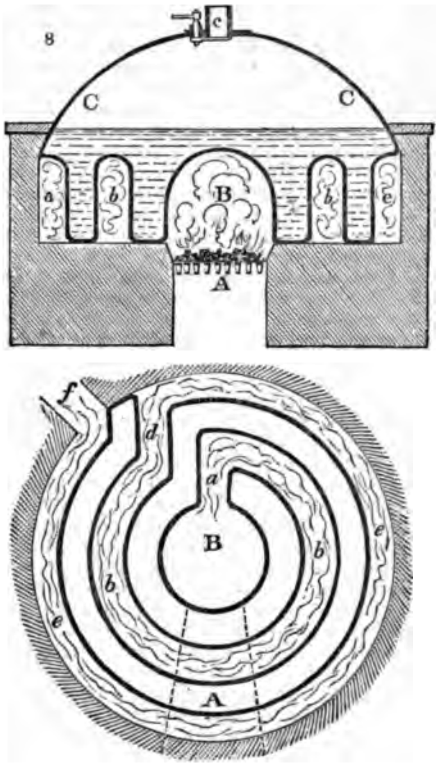


SMEATON'S HAYSTACK BOILER.



CATARACT.

The great expense of coals in Cornwall had the effect of causing a great variety of boilers to be tried there at a very early period of the history of steam improvement. Among other kinds, boilers built of moorstone and traversed by internal flues were constructed; but they do not appear to have been very successful, the fault probably being that the amount of flue surface was insufficient. The best boiler of this epoch that has fallen under our observation is that set up at the York Buildings' waterworks, in London, about the middle of the last century, and of which we here give a sketch. A is the ashpit; B the furnace; C C the boiler shell; *c* the steam-pipe; *a b d e* the flue winding spirally and entering the chimney at *f*.



BOILER AT YORK BUILDINGS ABOUT 1750.

But we have lingered too long among these antiquities, and have, we fear, tried the patience of our readers by dwelling upon contrivances about which nobody in these days of superior proficiency cares much. We suspect, too, that by saying so much about Smeaton we have, in some degree, damaged the keeping of our delineation; for an illegitimate extension of an object exaggerates its importance quite as effectually as too gaudy a colouring; and we really feel that Smeaton did nothing for the steam engine beyond what ordinary information and ordinary good sense might reasonably be expected to effect. The circumstance, however, that the atmospheric engine is not even yet a discarded instrument, but is still used in situations where coal is inexpensive, reconciles us in some measure to our prolixity; and we have been desirous, moreover, that our readers should have a just conception of the condition of the steam engine before the advent of Watt, in order that they might the more truly appreciate the merits of that mighty magician.

FROM THE COMPLETION OF THE IMPROVEMENTS OF SMEATON TO THE PRESENT TIME.

The steam engine, as it left the hand of Smeaton, was a mere pump impelled by the force of fire; and even in the performance of its solitary function of raising water, it could only be beneficially employed in situations where the cost of coal was inconsiderable. The transformation of this rude implement into the modern steam engine was the work of Watt; and certainly history can furnish no other example of so magnificent an improvement having been achieved by a single individual. In other cases amelioration has sprung out of a rich accumulation of experience, or out of the new facts presented to art by the progress of science: but Watt's improvements were the progeny of his own fertile imagination, and were brought to the perfection in which we now behold them by his own sagacity and perseverance.—We cannot, however, trust ourselves to say any thing upon a theme so attractive as Watt's genius at the present stage of our progress, as we fear we should afterwards be unable to speak of any thing else; and we have yet to relate the most remarkable steps in the history of his marvellous creations.

In 1763 Watt was a maker of philosophical instruments at Glasgow; and in that year Professor Anderson, who then filled the chair of natural philosophy, and who is known as the founder of the Andersonian Institution, from which the Mechanics' Institutions took their origin, sent Watt a model of a Newcomen engine to put into working order. The cylinder of this model was two inches in diameter, and the length of the stroke six inches, and the boiler was considerably larger in proportion than the boilers of real engines: but Watt found that the boiler did not supply the engines with steam enough; and, in order to enable the engine to work at all, he had to reduce the load on the piston by lowering the column of water in the pumps. There were only two possible solutions of this anomaly: the one, that the boiler was a bad one; and the other, that a small cylinder consumed more steam in proportion than a large cylinder on account of the loss by condensation due to an increased cooling surface; and the latter of these explanations was found to be the true one. The loss, however, from condensation was obviously attributable to two causes: the one, the radiation of heat from the cylinder; and the other, the refrigeration the cylinder suffered from the influent injection water. To determine the relative importance of these causes Watt made a small engine with a wooden cylinder, by which the refrigeration due to the transmission of heat through the cylinder would be prevented; but this species of cylinder appeared to be very little more beneficial in any way than the common kind, while, in some respects, it was of course greatly inferior. The greatest loss, therefore, appeared to be due to the heating and cooling of the cylinder: and to determine its precise amount Watt made a number of experiments to ascertain the relative bulks of the same weight of water and steam, and he found that the cylinder of his small engine consumed at every stroke three or four times the quantity of steam that would suffice to fill it. A great economy of fuel, therefore, it was obvious would be effected if the heating and cooling of the cylinder could be averted; and this was only to be done by accomplishing the condensation of the steam in a separate vessel, which might always be kept cold while the cylinder was always kept as hot as possible. A difficulty, however, presented itself in the accumulation within this vessel of the water by which the condensation of the steam had been effected, and which could not be driven out every stroke by snifting, as in the existing engine, without sacrificing all the gain the separate vessel conferred; but the water, it was clear, would run off of its own accord if led down a distance of about thirty feet, as that column of water would proponderate over the pressure of the atmosphere. The air, however, which had entered either by leakage or with the steam, could not be thus disposed of, but it might be removed by a pump wrought by the great lever, and that pump by dipping to the bottom of the condenser might also be made to extract the water, and thus supersede the necessity of running it off by the method first suggested. These views appear to have become developed in Watt's mind about the year 1765, he being at that time in the twenty-ninth year of his age, and his next step was to test their soundness by experiment. For this purpose he constructed a small engine, fitted with his various improvements, and its performance not merely confirmed, but greatly exceeded his anticipations. The next, however, and not the least difficulty, was to get the improved engine brought into operation, and three years appear to have elapsed before any serviceable step was taken in that direction. During this time Watt gave up his business as a mathematical instrument maker, and became a civil engineer, in which new capacity he happened to be employed by Dr. Roebuck, by whom the Carron iron works had been established, and he, on learning the nature of Watt's improvements on the steam-engine, agreed to join him in procuring a patent and establishing a manufactory of the improved engines, on the condition of being allowed two-thirds of the profits. To these terms Watt willingly agreed, and in 1769 he took out a patent for his improvements, the specification of which is as follows.

"My method of lessening the consumption of steam, and consequently fuel, in fire-engines, consists of the following principles:—

"First, That vessel in which the powers of steam are to be employed to work the engine, which is called the cylinder in common fire-engines, and which I call the steam-vessel, must, during the whole time the engine is at work, be kept as hot as the steam that enters it; first, by enclosing it in a case of wood, or any other materials that transmit heat slowly; secondly, by surrounding it with steam or other heated bodies; and thirdly, by suffering neither water or any other substance colder than the steam, to enter or touch it during that time.

"Secondly, In engines that are to be worked wholly or partially by condensation of steam, the steam is to be condensed in vessels distinct from the steam-vessels or cylinders, although occasionally communicating with them; these vessels I call condensers; and, whilst the engines are working, these condensers ought at least to be kept as cold as the air in the neighbourhood of the engines, by application of water, or other cold bodies.

"Thirdly, Whatever air or other elastic vapour is not condensed by the cold of the condenser, and may impede the working of the engine, is to be drawn out of the steam vessels or condensers by means of pumps, wrought by the engines themselves, or otherwise.

"Fourthly, I intend, in many cases, to employ the expansive force of steam to press on the pistons, or whatever may be used instead of them, in the same manner as the pressure of the atmosphere is now employed in common fire-engines. In cases where cold water cannot be had in plenty, the engines may be wrought by this force of steam only, by discharging the steam into the open air after it has done its office.

"Lastly, Instead of using water to render the piston or other parts of the engines air and steam tight, I employ oils, wax, resinous bodies, fat of animals, quicksilver, and other metals, in their fluid state.

"And the said James Watt, by a memorandum added to the said specification, declared, that he did not intend that any thing in the fourth article should be understood to extend to any engine where the water to be raised enters the steam-vessel itself, or any vessel having an open communication with it."

About the time he obtained his patent, Watt commenced the construction of his first real engine, the cylinder of which was 18 inches in diameter, and after many impediments in the details of the work, he succeeded in bringing it to considerable perfection. The bad boring of the cylinder, and the difficulty of obtaining a substance that would keep the piston tight without enormous friction, and at the same time resist the action of the steam, gave him most trouble, and the employment of a piston-rod moving through a stuffing-box was a new feature in steam-engines at that time, and required great nicety of workmanship to make it effectual. While Watt was contending with these difficulties, Roebuck's finances became disarranged, and in 1773 he disposed of his interest in the patent to Mr. Boulton, of Soho, near Birmingham, whose metal manufactory was already the most celebrated in England. As, however, a considerable part of the term of fourteen years, for which the patent was granted, had already passed away, and as several years more would probably elapse before the improved engines could be brought into operation, it was judged expedient to apply to Parliament for a prolongation of the term, and an act was passed in 1775, granting an extension of 25 years from that date, in consideration of the great merit of

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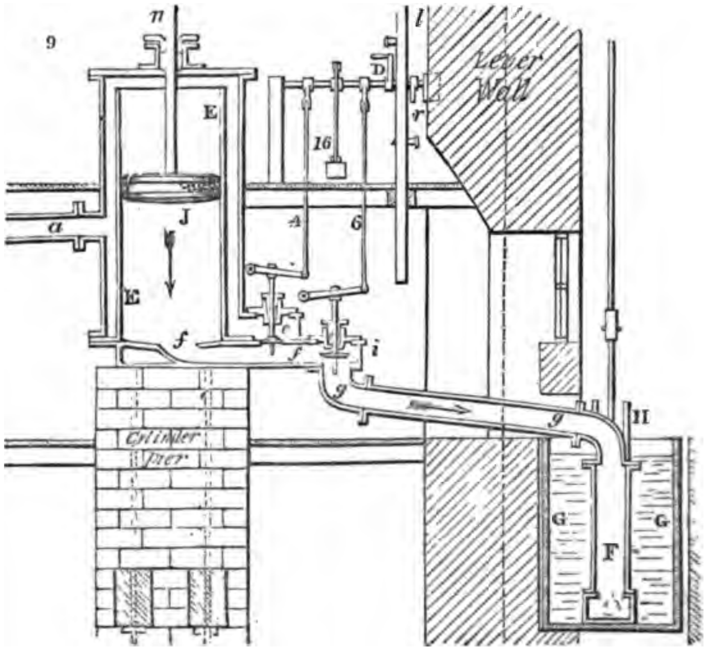

the invention. A partnership was then concluded between Boulton and Watt, and a part of Soho works was handed over to Watt for the manufacture of his engines. He now made rapid progress, and by 1778 had erected several excellent engines in the neighbouring counties, and one at Stratford near London. In these early engines he appears to have employed the method of condensing by external cold, and he persisted in the use of that species of condenser until the expense of its construction and the inconvenience of its bulk in the larger class of engines more than balanced the expenditure of power requisite to extract the injection water from a vacuum. The preceding diagram shews the manner in which Watt's improvements at this period of their history were applied to the ordinary pumping engines of the time, the substitution being restricted to the cylinder and its appendages, and the great lever, chains, pumps, and other parts remaining unaltered. E, E is the cylinder surrounded by a steam case, into which the steam is delivered by the steam-pipe *a;* J is the piston, loaded with a pressure of between 10 and 11 lbs. on the square inch, instead of 7½ as formerly, in consequence of the superior vacuum. *n* the piston-rod passing through a short tube affixed to the cylinder-cover, called the stuffing-box, and now cast in the same piece with the cover; *f, f,* the cylinder port; *e,* the steam valve; *i,* the eduction valve; *g, g,* the eduction pipe; F, the condenser, consisting of a number of copper cylinders of small diameter, arranged vertically in the cold water cistern G, G; H, the pump, by which the condensed steam is extracted from the condenser, and returned to the boiler; *l,* the plug-beam, in which are inserted two plugs, or tappets, which strike at the proper times the handles D and *r,* and thereby give the requisite movement to the steam and eduction valves, by the rods 4 and 6, with which those rods communicate; 16 is a weight which serves the same end as the tumbling bob in the old engines, in confirming the inclination given to the valve gear by the tappet. In the engine as thus constructed, the steam-casing is obviously an integral part of the machine; but this plan was found to be attended with some inconveniences, and in 1778 Watt contrived a way of removing this objection by the application of an upper port to the cylinder as shown in *fig.* 10, where E and J are the cylinder and piston as before; *a,* the steam-pipe; *b,* the regulating or throttling valve; *c,* the upper port; *f,* the under port; *d,* the prolongation of the steam pipe to the lower port; *e,* the equilibrium valve, by opening which the pressure above and below the piston is equalised; *i,* the eduction valve, and *g* the eduction pipe leading to the condenser. In this figure the piston is supposed to be in the act of ascending by virtue of the preponderance of the pump end of the beam, and the steam is leaving the space above the piston to occupy the space beneath it. When the piston has arrived at the top of the cylinder the equilibrium valve *e* is shut, and the eduction valve *i* is opened; the steam then rushes from beneath the piston to the condenser, but as the superior portion of the piston is still pressed on by the steam, the piston descends with a force corresponding to the difference of pressure above and beneath it.

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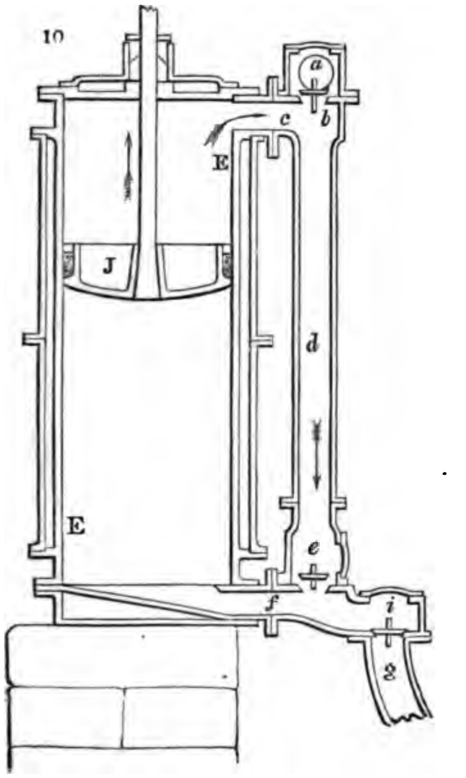

In this kind of engine there is always steam above the piston and steam and vacuum alternately beneath; but about 1780 it occurred to Watt, that the condensation might be made more perfect, and that a better result would therefore be realised if these conditions were reversed and a perpetual vacuum maintained beneath the piston, while an alternate steam pressure and vacuum was produced above it. In the one case the piston would ascend with steam of the same pressure on both sides, and in the other case with a vacuum of the same intensity; but in the one case the working stroke would be produced by the admission of steam above the piston, and in the other case by the exhaustion of the steam from beneath it. The arrangements adopted for carrying out these ideas are shown in the annexed delineation, where E E is the cylinder and J the piston as before, *a* the steam pipe, *b* the regulating valve, *e* the eduction and equilibrium valve, for in this variety of construction a single valve performs the functions of both; *c* the upper and *f* the under port; *d, j, g,* the eduction pipe by which the steam passes from above the piston during every returning stroke to the condenser, a perpetual exhaustion being maintained beneath it.

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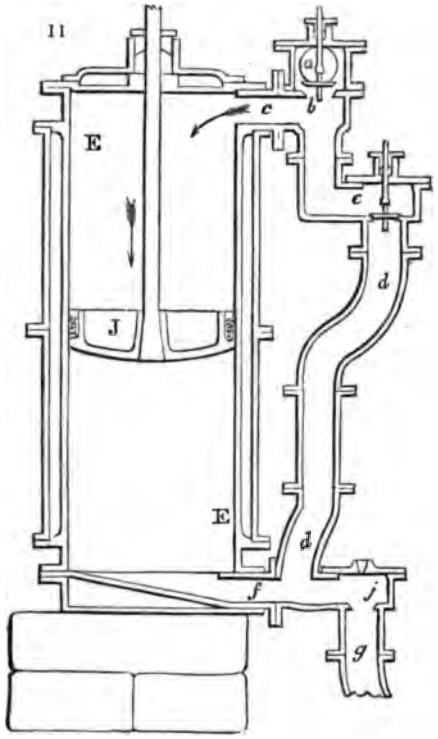

There was no advantage found to arise in practice from this ingenious transformation, but rather the reverse; for, although a longer time was thus obtained for the accomplishment of the condensation, yet the process of condensation is so rapid that this additional time was found to be of very little advantage; and whatever advantage was thus realised was to some extent only transferred from the working to the returning stroke, a heavier counterweight being necessary to redress any difference in the vacuum above and beneath the piston which might arise from a want of rapidity in the condensation. There was also a greater leakage of air at the stuffing-box and around the cylinder cover in this species of engine; and the rare steam or vapour, remaining in the cylinder after the act of exhaustion, had its elasticity increased by the heat transmitted from the steam jacket, thereby opposing more resistance to the piston, and robbing the effective steam of a portion of its heat. These disadvantages, taken singly, are all trivial enough, and indeed the sum of them is of no very serious import; yet, upon the whole, this species of engine appears to be somewhat inferior to engines of the ordinary kind, and it never, therefore, met with an extensive adoption. Boulton and Watt at this time charged their profits in proportion to the saving of fuel their engines effected, one third part of which was to be payable to them annually during the term of their patent, or the payment might be redeemed at a ten years' purchase. Their proposal was to raise 500,000 cubic feet of water one foot high by the consumption of 112 lbs. of Wednesbury coals, which is equivalent to about 23¼ millions of pounds raised one foot high by a bushel or 84 lbs. Their early engines, however, scarcely accomplished this; for two of them experimented on by Smeaton only lifted 18 and 18¼ millions of pounds one foot high with a bushel; but these were small engines. The larger engines appear to have realised a performance of about 20 millions; so that the following rule, laid down by Mr. Boulton in 1778, pretty nearly expresses the performance of the larger engines constructed by Boulton and Watt at that time. *Compute the area of the space described by the piston per stroke in cubic feet, and multiply this by the load* *upon each square inch of the piston in pounds; the product will be the weight of coals in pounds required to work the engine* 1800 *strokes.* This is equivalent to about 21¾ millions raised one foot high by a bushel of coal.

The next improvement of Watt's that we have to mention, is his plan of working steam expansively. This method consists in arresting the flow of steam into the cylinder at a certain part of the stroke, leaving the remainder of the stroke to be accomplished by the effort of the steam shut within the cylinder to occupy a larger volume. The power of the engine is of course diminished by this procedure; for the piston will descend with less force when urged merely by the diminishing effort of the expanding steam, than if pressed upon by steam of the full pressure entering to the end of the stroke from the boiler. But steam, or, in other words, fuel, is saved in a greater proportion than the power of the engine is diminished; so that the expansive principle augments, and very materially, too, the motive efficacy of the fuel. In fact, whatever power is obtained from the steam during the act of expanding is obtained without any expense; for if the steam valve of the cylinder be closed when half the stroke of the piston is performed, there will only be half the steam expended; but the steam shut within the cylinder will press with a varying force on the piston up to the end of the stroke, and the power thus realised is evidently got without any expenditure. We think it very probable that this improvement originated in the desire merely to moderate the force of the single acting engine towards the end of the stroke; and, indeed, Professor Robison, who, from his intimacy with Watt, was probably well acquainted with the circumstances of the discovery, virtually says that such was the case. In Newcomen's engine the momentum of the piston could easily be lessened by shutting the injection cock earlier or by opening it less, and dangerous shocks might thus be averted; but, in engines provided with a condenser, the impulse of the piston would be best checked by shutting the steam valve at such a period of the stroke as would prevent the catch-pins from striking. The realisation of an increased power, therefore, from a given quantity of steam by this expedient, was an unexpected result; but Watt immediately saw the importance of the principle, which in a letter from Glasgow in 1769 to Dr. Small, of Birmingham, he describes as capable of doubling the effect of the steam. The distractions, however, incidental to his other pursuits appear to have prevented him from carrying the principle of expansion into practice until 1776, when it was tried upon the engine at Soho, and in 1778 it was applied to an engine for raising water, erected at Shadwell. In 1782 Watt took out a patent for improvements in the steam engine, in which the principle of expansion formed a prominent feature, having been, probably, instigated to that act by a patent taken out by Hornblower in 1781 for a method of using the steam in an engine twice over; first impelling a small piston by the method of high pressure, propounded by Leupold, and then catching the steam thus used, and making it instrumental in giving motion to a larger piston by the method of condensation. This scheme is identical in principle with the plan of using the steam expansively, for it is obvious that the same power will be given out by a cylinder, whether it be tall and narrow, or short and wide, provided its capacity remains unaltered; and if we suppose Hornblower's high pressure cylinder to be shortened and widened, and set upon the top of his condensing cylinder, we shall then have a single cylinder operating on the plan of expansion, while the power is obviously the same as before this transformation.—The subject of expansion, however, is so important, and at the same time so mysterious to tyros in steam science, that it would be unpardonable to pass it over without offering such further familiar elucidations as may make the principle intelligible to unskilful persons, and we believe these explanations may be introduced here with greater propriety than at a more advanced stage of our progress.

It is a well-known law of pneumatics that the pressure of elastic fluids varies inversely, as the spaces into which they are compressed. For example, if a cubic foot of air of the atmospheric density be compressed into the compass of half a cubic foot, its elasticity will be increased from 15 lbs. on the square inch to 30 lbs. on the square inch, whereas if its volume be enlarged to two cubic feet, its elasticity will be diminished to 7½ lbs. on the square inch, being just the half of its original pressure. The same law holds in all other proportions, and with all other gases and vapours, provided their temperature remain unchanged; and if the steam valve of an engine be closed when the piston has descended through one-fourth of the stroke, the steam within the cylinder will, at the end of the stroke, just exert one-fourth of its initial pressure. Thus let E (*fig.* 12.) be a cylinder; J the piston, *a* the steam pipe, *b* the steam valve, *c* the upper port, *f* the lower port, *d* the steam pipe prolonged to *e* the equilibrium valve, *g* the eduction valve, M the steam casing, N top of cylinder, O stuffing box, *n* piston rod, P cylinder bottom: let the cylinder be supposed to be divided in the direction of its length into any number of equal parts, say twenty, and let the diameter of the cylinder represent the pressure of the steam, which for the sake of simplicity we may take at 10 lbs., so that we may divide the cylinder in the direction of its diameter into ten equal parts. If, now, the piston be supposed to descend through five of the divisions, and the steam valve then be shut, the pressure represented at each subsequent position of the piston will be represented by a series computed according to the laws of pneumatics, and which, if the initial pressure be represented by 1 will give a pressure of ·5 at the middle of the stroke, and of ·25 at the end of it. If this series be set off on the horizontal lines they will give a hyperbolic curve, the area of the part exterior to which represents the total efficacy of the stroke, and the interior area therefore represents the diminution in the efficacy of a stroke when the steam is cut off at one fourth of the descent. If the squares above the point where the steam is cut off be counted, they will be found to amount to 50, and if those beneath that point be counted or estimated they will be found to amount to about 68, and these squares are representative of the power exerted, so that while an amount of power, represented by 50, has been obtained by the expenditure of a quarter of a cylinder full of steam we get an amount of power represented by 68 without any expenditure of steam at all, merely by permitting the steam first used to expand into four times its original volume. The efficacy of a given quantity of steam is therefore more than doubled by expanding the steam four times, while the efficacy of each stroke is made nearly one half less; and therefore to carry out the expansive system in practice the cylinders require to be larger than usual in the proportion to which the expansion is carried. Every one who is acquainted with simple arithmetic can compute the terminal pressure of the steam in a cylinder when he knows the initial pressure and the point at which the steam is cut off, and he can also find by the same process any pressure intermediate between the first and the last. By setting down these pressures in a table, and taking their mean, he can easily determine the effect with tolerable accuracy of any particular measure of expansion, of which the mean pressure thus determined will be the representative. We shall, however, at the proper place give practical rules for computing the effect of expansion at a single step: at present we aspire to accomplish nothing more than to convey a few general ideas on the subject to those who are not familiar with such inquiries; and as a summary of the ascertained effects of expansion will probably induce a more careful examination of the principle at a future stage of our progress, we may here set down some of the most notorious.

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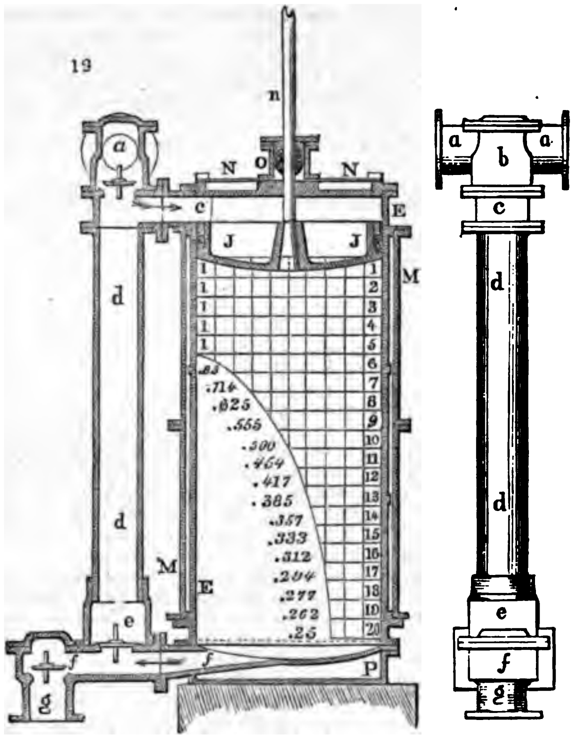
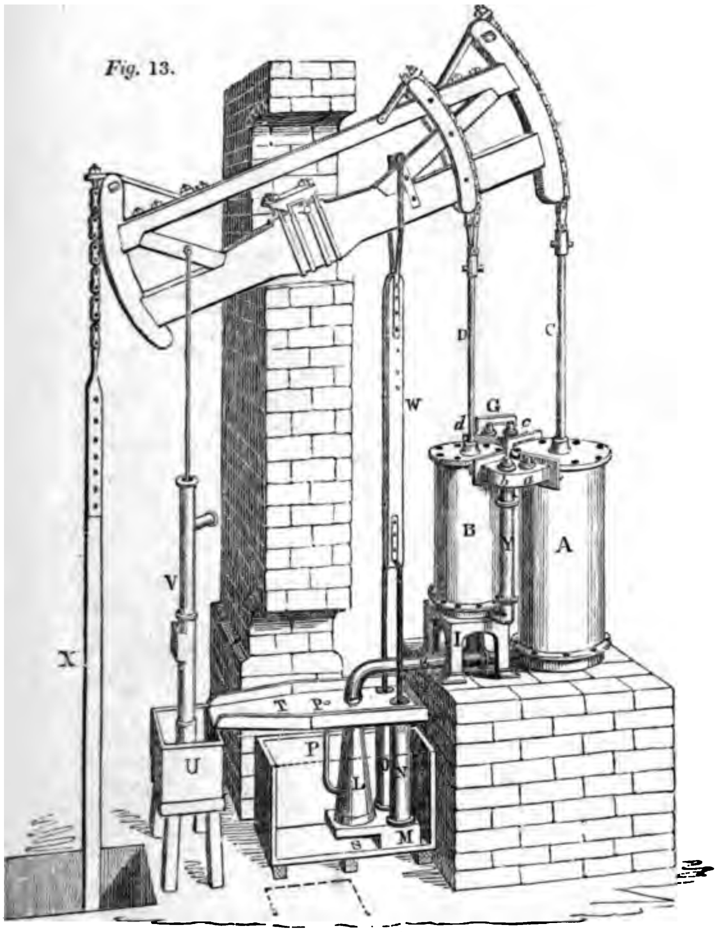


Let the steam be stopped at	Its performance is multiplied
½	1·7
⅓	2·1
¼	2·4
⅕	2·6
⅙	2·8
⅐	3·
⅛	3·2

A forty-horse engine, constructed by Mr. Watt about the time of the introduction of his expansive principle, was found to require about 8½ lbs. of coal per horse-power per hour when working without expansion, and about 6¼ lbs. when the expansion was 1·518 times. The water evaporated from the boiler was, without expansion, ·674 cubic feet per minute; and, with the amount of expansion already mentioned, ·501 cubic feet per minute: and the quantity of injection water was, without expansion, 19·3 cubic feet per minute, at a temperature of 52 degrees; and, with the expansion aforesaid, 14·35 cubic feet.

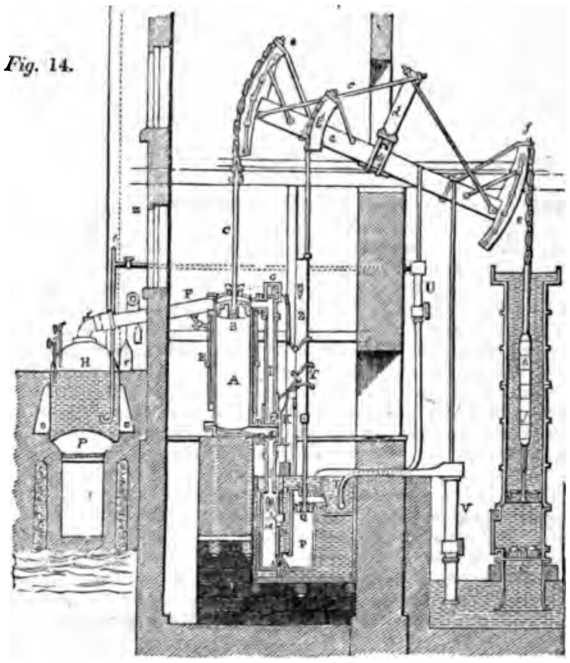
Fig. 13.



HORNBLOWER'S ENGINE.

Previous to the introduction of Boulton and Watt's engine into Cornwall, Mr. Jonathan Hornblower had been one of the principal makers of engines for that district; and he appears to have made very strenuous efforts to prevent himself from being driven out of so profitable a market. In 1781 he took out a patent, as we believe we have already mentioned, for a double cylinder engine, which is said to have been invented in 1776. The form of this engine will be understood at once by a glance at the accompanying sketch (*fig.* 13.), where A is the larger cylinder; B the smaller one; C and D their respective piston rods; G a square pipe for supplying the small cylinder with steam from the boiler; K is the eduction pipe leading to the condenser, L, which stands on the box, M, and to which are fixed the pumps O and N, for extracting the air and water; P is a cold water cistern in which the condenser stands; U is the hot well to which the water is conveyed from the air pumps by the trough, T; and into the hot well the feed pump V dips to obtain water for the boiler; W is the plug rod; and X the pump rod of the mine. At S a valve is situated to admit cold water into the condenser; and *p* is a pipe leading from the condenser, closed on the top with a valve which serves as a blow-through valve. *a b c d* are cocks, two of which are the reciprocal of the other two, and which establish the requisite communications between the boiler and the cylinders. When *d* and *a* are open, and *b* and *c* are shut, the steam from the boiler enters through *d* above the piston of B, and the steam from beneath the piston of B enters, above the piston of A, through *a*. At the same time the valve situated in the eduction pipe, where it joins the cylinder, is open, and the engine makes a stroke. Again, when *b* and *c* are open, and *a* and *d* shut, a communication is established between each side of the respective pistons; and, as an equilibrium of pressure is thus produced, the pistons rise by virtue of the preponderance of the pump end of the beam. There is a great deal of manifest plagiarism in this engine: the condenser and air pump, the cylinder covers with their stuffing boxes, and indeed every thing good about the engine, is evidently borrowed from Mr. Watt, with the single exception of the two cylinders; and by them nothing was accomplished that had not been already attained by Mr. Watt quite as effectually with a single cylinder only. The plan of two cylinders is still sometimes used in cases requiring a great equability of motion, or where the principle of expansion is carried to an unusual extent; for the initial impulse is less vehement on the double cylinder plan than where the expansion is accomplished in a single cylinder, while the mean impelling force remains the same. There is thus less tendency for the motion to become irregular, and less risk of fracture from the extra pressure of steam requisite to maintain the power of an engine when working expansively. But there is no theoretical gain by the use of two cylinders, and there is certainly greater complexity, while experience shows that an engine constructed on the common proportions is strong enough to be capable of working up to its power at all ordinary degrees of expansion, and the motion may be rendered uniform enough for most purposes by the use of a short stroke and a swift and heavy fly wheel. There are cases, nevertheless, in practice in which we think two cylinders are to be preferred to one, but their number is by no means considerable, and they lie very little among the class of pumping engines. Several excellent pumping engines, indeed, of the double cylinder description have been erected in Cornwall; and some, we believe, are being constructed there at the present moment, with the view, we suppose, of carrying the principle of expansion very far, without involving the necessity of making the parts of the engine inconveniently strong. But the same end might, we conceive, be attained as effectually, and with greater ease, by increasing the length of the stroke; and in a pumping engine uniformity of motion is an object of but little importance.

Fig. 14.

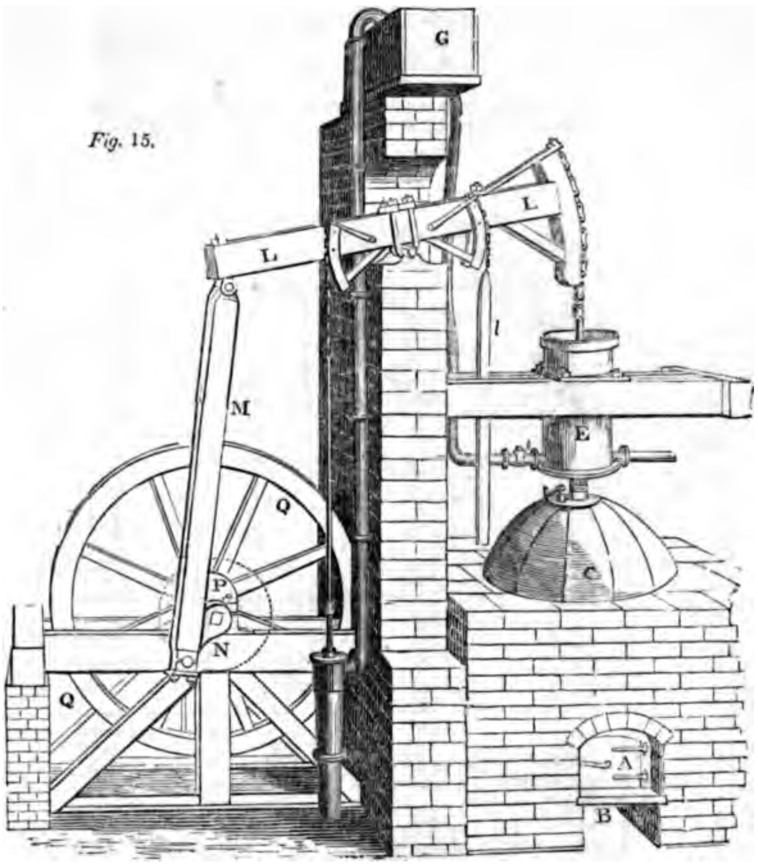


WATT'S SINGLE-ACTING ENGINE.

The form Mr. Watt's engine had attained about the period at which we have now arrived is shown in the following figure, where A is the cylinder, B the piston, C the piston rod, E the cylinder steam casing, F the steam pipe, G the steam valve, by which the admission of steam to the cylinder is restrained or prevented, H the boiler, I the prolongation of the steam pipe to the equilibrium valve K, L the eduction valve, M the condenser, J the eduction pipe, N the injection cock, O the foot valve, P the air-pump, Q the air-pump bucket, S the delivery valve, communicating with the hot well, T the suction pipe of the feed pump, U the feed pump, V the cold water pump for lifting the injection water into the cold water cistern, Y the valve handles, which are moved by tappets on the plug-tree, Z, suspended from the beam; *a* is the body of the beam, *b* the main centre; *c, c,* truss rods, proceeding from the central upright, *d*, to each end of the beam, to obviate deflection; *e, f* arch heads, to which the chains of the piston rod and pump rod accommodate themselves, *g* a small arch head for giving motion to the air-pump bucket, on the rod of which the plug tree is affixed; *h, j* counter-balance weights; *k*, suction valve of the pump; *o, o,* flues encircling the boiler; *p* furnace; *r* damper in the flue leading to the chimney. The manner in which this engine operates is easily comprehended. In this as in the atmospheric engine, the piston necessarily stands at the top of the cylinder when the engine is at rest, in consequence of the preponderance given to the pump end of the beam, and the first step in starting the engine is to expel the air with which the space beneath the piston, and the several pipes and passages have become filled. This is accomplished by relieving the handles of the steam, equilibrium, and eduction valves, of their several catches, when the valves immediately fall open by the gravitation of weights with which they are connected, and the steam finds an access to the whole internal part of the engine. At first it is rapidly condensed by coming into contact with the cold metal; but as the iron becomes hot the steam flows onward, expelling the air before it, and finally issues at the snifting or blow valve, situated on the lower part of either the air-pump or condenser. The valves must now be shut, and a vacuum will quickly be produced within the engine by the condensation of the steam. The blowing through may be repeated two or three times, in order to expel the air effectually, and the symptom of its thorough expulsion is the sharp crackling noise made by the steam at the snifting valve, which is caused by the rapid condensation of the steam when unmixed with air by the water suffered to lie in the snifting valve chest to keep the valve tight. When the engine has been thoroughly cleared of air by blowing through, the steam and eduction valves are opened at the same time, the equilibrium valve remaining shut, and the injection cock is also opened. The steam then pressing upon the superior surface of the piston while there is a vacuum underneath it, forces the piston down. The plug-tree in its descent closes the steam and eduction valves,and opens the equilibrium valve, which establishes an equality of pressure above and beneath the piston, and the piston then rises in consequence of the pump end of the beam being the heaviest. The plug-tree in its ascent closes the equilibrium valve, and opens the steam and eduction valves, and the action is thus perpetuated. The water admitted by the injection cock is discharged by the pump, P, into the hot well S, from whence a sufficiency of water is drawn by the small pump U, to replenish the boiler. No improvement in the principle of the simple-acting or pumping engine has taken place since its parts were arranged by Watt in the manner here delineated. The great lever indeed is now made of iron instead of wood, parallel motions are employed instead of arch heads and chains, and some improvements have been made in the details of the valve gearing and other minutiæ. But these modifications, though they may make the instrument more elegant and convenient, do not make it more effectual; and an engine made after Watt's primitive type would with an equally effectual boiler, and an equal measure of clothing and expansion, do about the same amount of duty as the best of the modern constructions.

We have already mentioned that Boulton and Watt charged their profits not on the manufacture of engines, but on the actual saving their engines effected, the agreement for the use of them being such that the patentees became entitled to one third of the saving in fuel accomplished by the new invention. Their gains were thus in the proportion simply of the benefit they conferred, and the amount of that benefit may be judged of from the fact that the proprietors of the Chase Water mine found it to their advantage to commute the proportion of saving due to the patentees for 2,400*l.* per annum. These payments, however, gradually came to be looked upon as an intolerable burden by the mine owners, though the burden must obviously have been three times less grievous than under the former state of things; but by some infirmity of human nature, men who respect the rights of all other property, will often seize without compunction upon that which has sprung out of the highest order of mental exertion; and of all manufacturers there is no kind whose wares are paid for with so much reluctance as the manufacturer of ideas. The Cornish miners paid the proportion of savings due to the patentees, with the unwillingness natural to men who conceived that nothing had been done to earn such rewards, and many of them eagerly sought for a pretext to break the agreement into which they had entered. They countenanced and supported a set of pirates who left no means untried to wrest Mr. Watt's invention from his grasp; and so formidable did this confederacy become, that, in the imperfect state of the patent laws which then obtained, Mr. Watt appears to have entertained serious doubts of his ability to maintain his rights. The machinations of this cabal reached a head in 1795, in which year, after infinite forbearance, the patentees were obliged to bring an action against a Mr. Bull by whom several of the mine-owners were represented, for the erection of an engine on Mr. Watt's plan at Oatfield copper mine in Cornwall. The pirates contended, as is usually done in the lack of better argument, that the patent was informal from the want of precision in the specification; a dishonourable plea at the best, for no honest person would attempt to seize upon the property of another, merely on account of a technical flaw in the title. Two of the judges however, called Buller and Heath, thought this pitiful objection of weight; though Lord Chief Justice Eyre and Justice Rooke looked upon it as immaterial. As the Court was divided equally, no judgment was given; and this being looked upon as a sort of defeat, several other infringements were begun. In 1799 however the patentees commenced another action for infringement in the Court of Common Pleas, which on this occasion was against Messrs. Hornblower and Maberly, and a verdict was given for the plaintiffs. A similar case was tried in the Court of King's Bench, and the judges there were unanimous in supporting the rights of the patentees against the cupidity of the litigious highwaymen who aspired to legalize their robberies. It is incomprehensible to us, how a man of ingenuity, which Hornblower certainly was, could descend to such arts as attempting to rob a brother mechanic of the fruits of his ingenuity and perseverance; and we are still more at a loss to account for the bitter hostility displayed by Bramah throughout these trials; who tried hard to make it clear that Mr. Watt had no right to any patent whatever! If Mr. Watt had no such right, who in the name of heaven ever had? and of what rich gifts would not universal humanity have been defrauded, if Watt had been discouraged from proceeding farther at the commencement of his career of improvement! It is the steam-engine says a kindred spirit,* that fought the battles of Europe, and which now enables us to maintain the arduous struggle in which we are still engaged with countries less oppressed with taxation; so that upon the slender thread of Watt's prosperity, which a court of law might have rudely severed, hung the welfare of nations, and the repose of the world. Fortunately for human nature, Watt's puny rival Bramah was not his judge; and the difficulties thrown in his path as they were insufficient to impede his progress only stimulated his powers to a more active exertion. It was the Cornish conspiracy in all probability, that made Watt turn his attention to the invention of an engine for the production of a rotatory motion, so that he might continue to enjoy the fruits of his ingenuity, even though driven from the Cornish field. Of this invention we must now proceed to give some account, but may first enumerate the more notable projects for the production of rotatory motion, both before and after the time of Watt; for although the date of some of these devices is more recent than that of Watt's invention they are all more antiquated in point of quality.

Fig. 15.



ATMOSPHERIC ENGINE WITH CRANK AND FLY-WHEEL, 1780.

Savery and Papin both proposed the production of a rotatory motion by means of their machines, and in 1736 Jonathan Hulls proposed to propel a boat by the agency of paddle wheels moved by a Newcomen engine. In 1759 Mr. Kean Fitzgerald proposed to supply mines with air by means of a revolving fan, wrought by a Newcomen engine, and in 1777 Mr. John Stewart described a plan for converting rectilinear into circular motion, in a paper read before the Royal Society, and in which he incidentally mentions the use of a crank, but rejects the idea as being impossible in practice. In 1779 Mr. Matthew Washbrough took out a patent for the production of a continuous circular motion by the application of ratchet wheels. Indeed in all the plans we have mentioned, ratchet wheels or some analogous contrivance, by which a wheel was carried round a certain distance during the descent of the piston,—the catches being either inoperative during the ascent, or made to act upon ratchets disposed in the contrary direction,—appear to have been the instruments; but in 1780 the ratchet work of one of Mr. Washbrough's engines, which had been erected at Birmingham, was removed by the persons who had the care of the engine, and a simple crank substituted in its stead. There can be no doubt we think, from what Mr. Watt says on this subject, that the idea of the crank *leaked out* from Soho. The ratchets were found to be extremely troublesome to keep in order; and the people in the charge of the engine were very likely to adopt any remedy that was thought to be sanctioned by so high an authority as Mr. Watt. In 1780 a patent was taken out by Mr. Pickard of Birmingham for a method of deriving a rotatory motion from a fire-engine by the intervention of a crank. The

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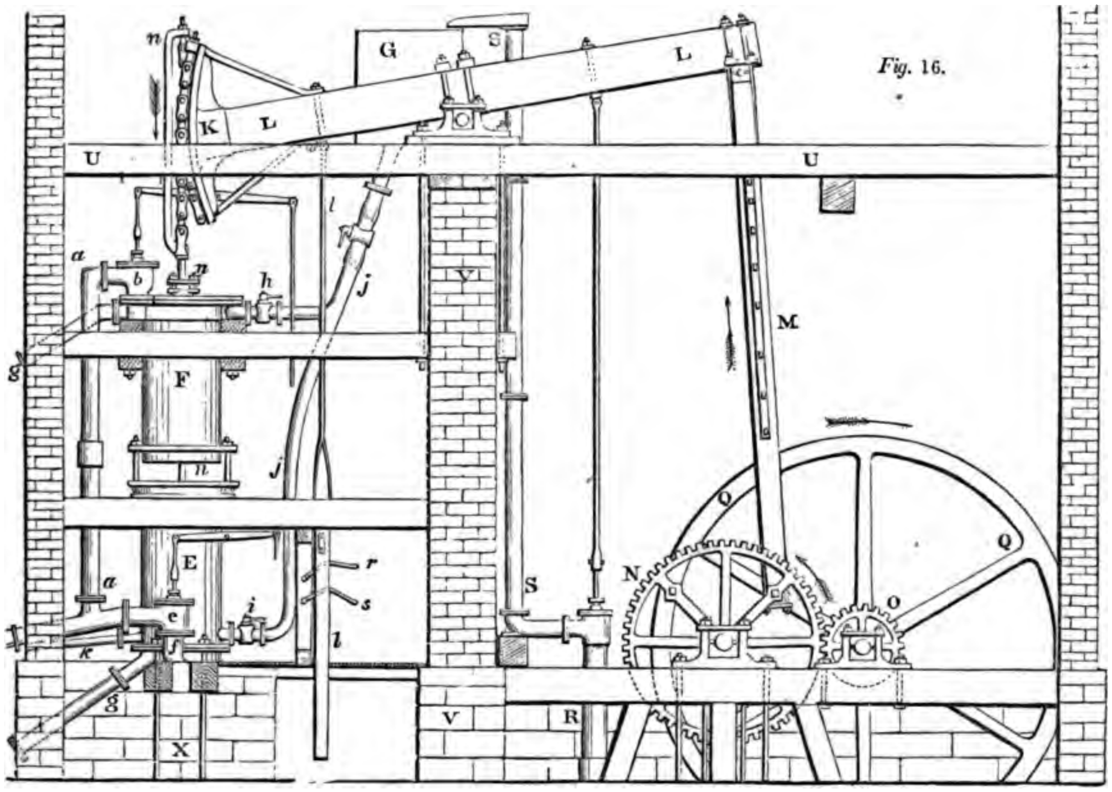
* Lord Jeffrey.



THOMPSON'S DOUBLE-ACTING ATMOSPHERIC ENGINE, 1793.

engine is not represented in the specification of his patent, but the sketch given in *fig.* 15. will explain in what manner the crank was applicable to the common atmospheric engine.

A is the furnace, B the ash-pit, C the boiler, E the cylinder, L the great lever, G the injection cistern, M the connecting rod, N the crank, Q the fly-wheel, *l* the plug-tree which gives motion to the valves. It is obvious that this engine can only give an impulse to the fly-wheel during its downward stroke, but the energy then imparted to the fly-wheel will continue the motion with considerable uniformity during the ascent of the piston.

To add to the regularity of the motion, in the case of a crank applied to an engine on the atmospheric plan, Mr. Francis Thompson of Ashover, in Derbyshire, contrived about 1793 a plan of combining two cylinders so as to produce a double action. The foregoing representation shows the nature of his arrangements:— E (*fig.* 16.) is the ordinary cylinder, and F an inverted cylinder situated above it with a space, *n*, between the cylinders to permit the access of the atmosphere to press upon the pistons. L L is the main lever, and K the arch head which is connected with the piston rod by double-acting chains through the medium of a bridle, so that the piston rod may communicate an upward as well as a downward motion to the lever. There are three chains in all — two, for pulling the lever down, and one for pulling it up. G is the cold water or injection cistern, which receives its water from the pump R, through the pipe S; V is the lever wall, U the spring beams, and X a solid pier of masonry on which the lower cylinder rests. M is the connecting rod which turns the wheel, N, working into the pinion O, on the shaft of the fly-wheel Q, thereby giving an increased energy to the fly-wheel by its augmented velocity. *a* is the steam pipe, *b* and *c* the steam valves, *f* a passage leading from the steam valve into the lower cylinder, *g g* eduction pipes, *h*, *i* the injection cocks, *j* the injection pipe leading from the elevated cold water cistern, *k* a snifting valve to the lower cylinder, and there is a similar valve attached to the upper cylinder, but it is not shown; *l* the plug rod which gives motion to the valve handles, *r* and *s*, by which the ingress of the steam and injection water into the cylinder is duly regulated. A large engine on this plan was set up by Mr. Thompson at Arnold near Nottingham, to drive a spinning mill, and it accomplished its task successfully for many years, though with a large consumption of fuel. The cylinders were 40 inches in diameter, the length of the stroke 6 feet, and the number of strokes per minute 18. Very few similar engines, however, have since been constructed, as they were found quite as difficult to keep in good order as the more refined engines of Boulton and Watt, and far more extravagant in fuel.

Another double-acting atmospheric engine, of a different construction, but also employed for spinning cotton, was erected in Manchester by Messrs. Sherratts about 1794. The idea of the double-acting mechanism of this engine is evidently taken from the double-acting air pump, as constructed by philosophical instrument makers; and of the rest of the plan the greater part is pirated from Mr. Watt. E E (*fig.* 17.) are the cylinders open at the top, J J the pistons, K K the piston rods, which are toothed, and work into the wheel L L, which answers the purpose of the great lever. *l l* are racks for giving motion to the air pumps, and which work into the smaller wheel 7, 7, situated on the same axis as L. P is a lever also fixed on the same axis *p*, and which, by means of the connecting rod M, imparts motion to the crank, N, fixed on the shaft of the fly-wheel Q. *a a* is the steam pipe with a middle branch, *d*, descending in an inclined direction to the box holding the steam valves *f f*, and beneath which are two eduction valves communicating with the eduction pipe *g*. F is the condenser, *k* the foot valve, H H the air pumps, I I the hot well, G G the cold water cistern; U U are strong beams for supporting the axis, *d*, of the wheel L, X X strong beams for supporting the cylinders, and Z a throttle valve in the descending branch, *d*, of the steam pipe, to regulate the flow of the steam. The cylinders of this engine were 36 inches in diameter, and the length of the stroke 4 feet. At first the engine made 40 strokes per minute, but its speed was afterwards reduced to 30 strokes per minute. It continued to work constantly for upwards of 30 years, but its proprietors had to pay Messrs. Boulton and Watt for a licence to use it, in consequence of the large adoption of their improvements. The use of the rack work is not so objectionable as might at first sight appear, as the pressure on the teeth is always in the same direction, provided steam of no higher tension than the atmosphere be used, and there is therefore no back-lash between the teeth.

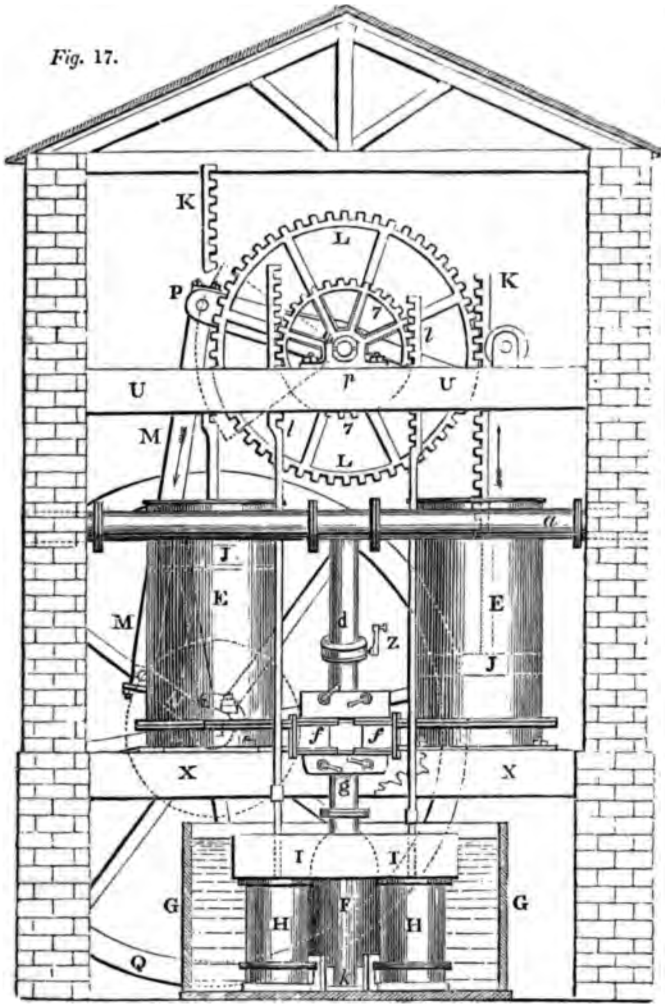
The only other engine we shall notice before proceeding to describe Mr. Watt's rotative engine is the engine of Mr. Edmund Cartwright, patented in 1797. The following are the improvements enumerated in his specification:—

"1st. The water or other liquid which is used to produce the steam to work the engine is to circulate continually through the engine, without having any communication with the external air, and without mixing with any other fluid.

"2nd. The lower part of the cylinder is to be always open to the condenser, and the condensation is to be performed during the returning stroke of the piston, which has only a single action. There are to be only two valves, one at the top of the cylinder, and the other in the piston; and these valves are to be opened and shut at the proper intervals, by the motion of the piston itself.

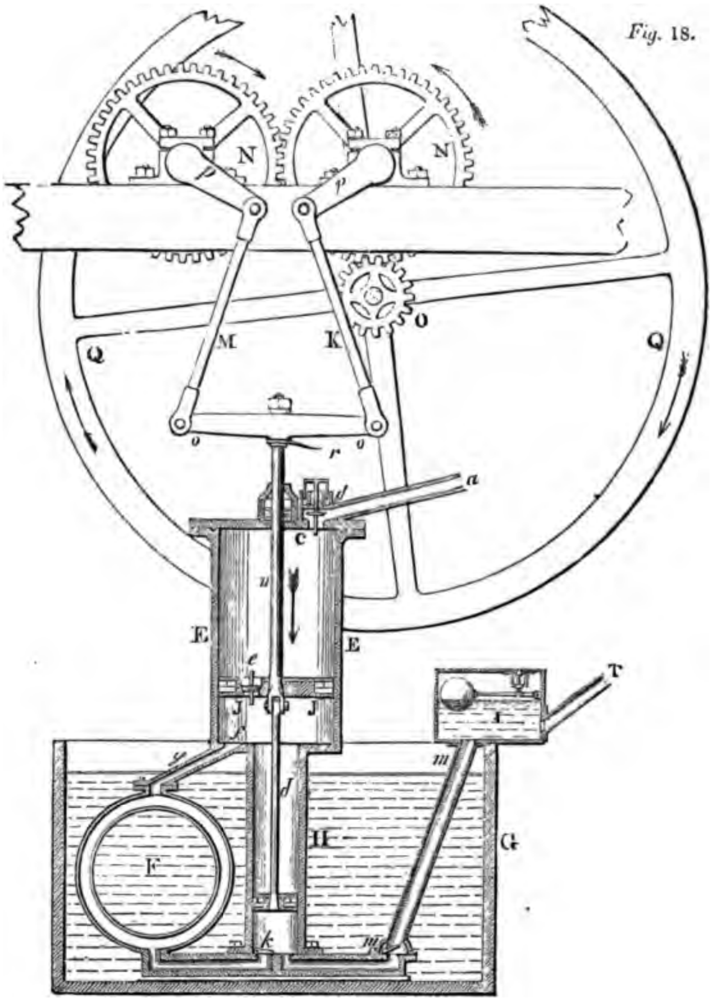
"3rd. The condensation is to be performed in a close vessel by the application of cold water to the external surface of that vessel on the common principle of distillation, without any injection of cold water into it. The condenser is to be composed of two cylinders of very thin metal, one fixed within the other, so as to leave a very narrow space between them for the steam. This condenser is to be immersed in cold water, which is to surround the outside cylinder, and to fill the internal cylinder, whereby a very thin stratum of steam will be exposed to a large surface of cold metal. The condensed liquid which drains to the bottom of the condenser is to be drawn

Fig. 17.



DOUBLE-ACTING ATMOSPHERIC ENGINE, 1794.

Fig. 18.



CARTWRIGHT'S ENGINE, 1797.

out by a suitable pump, and returned into the boiler, any air which may get into the condenser being separated from the water before it reaches the boiler, and discharged into the open air.

"4th. The piston is to be made entirely of metal, without any hemp packing.

Lastly. Instead of water the boiler is to be filled with distillers' wash, to produce the steam with which the engine is to be worked."

The structure of this engine will be made apparent by the annexed delineation. E E (*fig.* 18.) is the cylinder, and J J its piston, which is in the act of descending. C is the steam valve situated in the cylinder cover, and enclosed in the box *d*. F is the condenser; H the air pump, the piston of which operates by expression; G the cold water cistern; O a pinion situated on the shaft of the fly-wheel Q Q, and moved by the wheels N N. To the axes of these wheels are affixed the cranks *p p*, connected with the cross head *o o*, by the rods M and K. *a* is the steam pipe, *r* a small spring affixed to the upper end of the piston rod for shutting the steam valve, when the piston has descended sufficiently; *n* is the piston rod, *f*, *g* the eduction pipe, *k* the foot valve, *m* the discharging valve and pipe, through which the condensed steam which enters the air pump during the ascent of the piston is expelled into the hot well I. A float is placed in the hot well, communicating with a small inverted valve, and should any air enter the engine by leakage it will accumulate in the hot well, and depress the water level, which will open the valve and allow the air to escape. T is a pipe which conveys the water from the hot well to the boiler. The valve in the piston is opened by its spindle touching the bottom of the cylinder, and the spindles of both it and the steam valve are pressed laterally by springs, so as to occasion sufficient friction to retain the valve in the position in which it may be set. There is a great deal of ingenuity displayed in this combination, but the devices are more elegant than feasible, and engines made on this plan were not found to work well. The refrigerating surface in the condenser is much too small, and the air would accumulate beneath the air pump piston, and impair the vacuum. Another obvious disadvantage is, that the pressure of the steam in the boiler is thrown upon the air pump piston so soon as the discharging valve is opened, which must occasion an unusual strain upon the air pump if the pressure of the steam be considerable. Metallic pistons are now common; but that contrivance had previously occurred to Mr. Watt: and there is nothing else that is good in this kind of engine, and all of Cartwright's engines that were made have either been discontinued or broken up.—But we must now return from the contemplation of these imperfect contrivances to the proceedings of Watt, to whose unaided ingenuity we are indebted for the double-acting steam-engine as we now find it. We cannot do better than give in his own words the several steps of the invention.

"I had very early turned my mind to the producing continued motions round an axis; and it will be seen, by reference to my first specification in 1769, that I there described a steam-wheel, moved by the force of steam acting in a circular channel against a valve on one side, and against a column of mercury, or some other fluid metal, on the other side. This was executed upon a scale of about six feet diameter at Soho, and worked repeatedly, but was given up, as several practical objections were found to operate against it. Similar objections lay against other rotative engines which had been contrived by myself and others, as well as to the engines producing rotatory motions by means of ratchet-wheels. Having made my reciprocating engines very regular in their movements, I considered how to produce rotative motions from them in the best manner; and amongst various schemes which were subjected to trial, or which passed through my mind, none appeared so likely to answer the purpose as the application of the crank in the manner of the common turning lathe (an invention of great merit, of which the humble inventor, and even its era, are unknown). But, as the rotative motion is produced in that machine by the impulse given to the crank in the descent of the foot only, and behoves to be continued in its ascent by the momentum of the wheel, which acts as a fly, and being unwilling to load my engine with a fly heavy enough to continue the motion during the ascent of the piston (and even were a counterweight employed to act during that ascent of a fly heavy enough to equalise the motion), I proposed to employ two engines acting upon two cranks fixed on the same axis at an angle of one hundred and twenty degrees to one another, and a weight placed upon the circumference of the fly at the same angle to each of the cranks, by which means the motion might be rendered nearly equal, and a very light fly only would be requisite. This had occurred to me very early; but my attention being fully employed in making and erecting engines for raising water, it remained *in petto* until about the year 1778 or 1779, when Mr. Washbrough erected one of his ratchet-wheel engines at Birmingham, the frequent breakages and irregularities of which recalled the subject to my mind, and I proceeded to make a model of my method, which answered my expectations; but having neglected to take out a patent, the invention was communicated by a workman employed to make the model to some of the people about Mr. Washbrough's engine, and a patent was taken out by them for the application of the crank to steam engines. This fact the said workman confessed; and the engineer who directed the works acknowledged it, but said, nevertheless, the same idea had occurred to him prior to his hearing of mine, and that he had even made a model of it before that time, which might be a fact, as the application of a single crank was sufficiently obvious. In these circumstances I thought it better to endeavour to accomplish the same end by other means than to enter into litigation, and if successful, by demolishing the patent, to lay the matter open to every body. Accordingly, in 1781, I invented and took out a patent for several methods of producing rotative motions from reciprocating ones, amongst which was the method of the sun and planet wheels.

" This contrivance was applied to many engines, and possesses the great advantage of giving a double velocity to the fly; but is, perhaps, more subject to wear, and to be broken under great strains, than the crank, which is now more commonly used, although it requires a fly-wheel of four times the weight, if fixed upon the first axis. My application of the double engine to these rotative machines rendered unnecessary the counter-weight, and produced a more regular motion; so that, in most of our great manufactories, these engines now supply the place of water, wind, and horse-mills; and instead of carrying the work to the power, the prime agent is placed wherever it is most convenient to the manufacturer.

" I do not exactly recollect the date of the invention of the double engine, but a drawing of it is still in my possession, which was produced in the House of Commons when I was soliciting the act of Parliament for the prolongation of my patent in 1774 and 1775. Having encountered much difficulty in teaching others the construction and use of the single engine, and in overcoming prejudices, I proceeded no further in it at that time, nor until finding myself beset with a host of plagiaries and pirates in 1782, I thought it proper to insert it, and some other things, in the patent abovementioned.

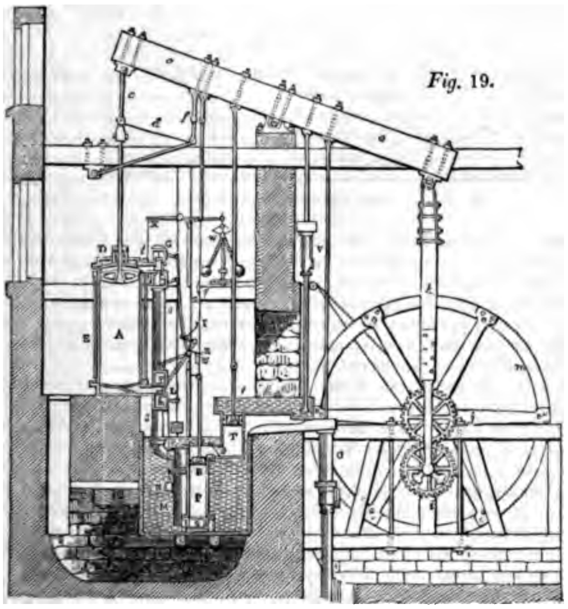


Fig. 19.

ALBION MILLS ENGINE.

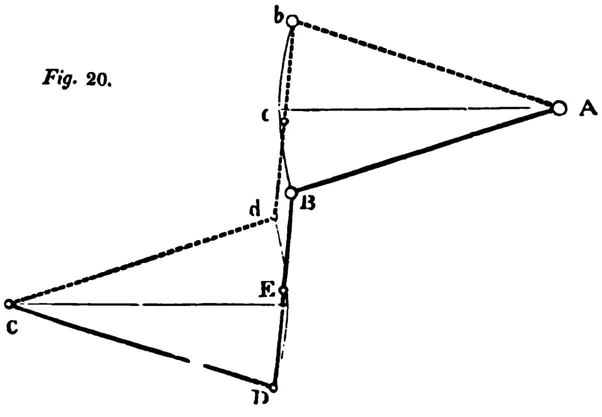
" *Fig.* 19. is a vertical section of one of the Albion Mill engines. The steam-pipe conveys steam from the boiler to the cross-pipe, or upper steam-nozzle G, and by the perpendicular steam-pipe to the lower steam-nozzle. In the nozzle G is a valve, which, when open, admits steam into the cylinder above the piston through the horizontal square pipe at its top; and in the lower steam-nozzle there is another valve, which, when open, admits steam into the cylinder below the piston. In the upper exhaustion-nozzle is a valve, which, when open, admits steam to pass from the cylinder above the piston into the exhaustion-pipe J, which conveys it to the condensing-vessel M, where it meets the jet of the injection from the cock N, and is reduced to water; and, in the lower exhaustion-nozzle, there is also a valve, which, when open, admits steam to pass out of the cylinder below the piston, by the eduction-pipe, into the condenser M.

" The piston being at the top of its stroke, the valves G and L are to be opened, and the fly-wheel *m* turned by hand about one-eighth of a revolution, or more, in the direction in which it is intended to move; the steam which is then in the cylinder will pass by L into the condenser, when, meeting the jet of water from the injection-cock, it will be converted into water, and the cylinder thus becoming exhausted, the steam, entering the cylinder by the valve G, will press upon the piston and cause it to descend, while, by its action upon the working beam through the piston-rod, &c., it pulls down the cylinder end of the beam, and raises up the other end and the connecting rod *h*, which causes the planet-wheel, *i*, to tend to revolve round the sun-wheel *j*; but the former of these wheels, being fixed upon the connecting-rod so that it cannot turn upon its own axis, and its teeth being engaged in those of the sun-wheel, the latter, and the fly-wheel, upon whose axle or shaft it is fixed, are made to revolve in the desired direction, and give motion to the mill-work.

" As the piston descends, the plug-tree, Z, also descends, and a clamp or slider, *q*, fixed upon the side of the plug-tree, presses upon the handle, I, of the upper Y-shaft or axis, and thereby shuts the valves G and L; and the same operation, by disengaging a detent, permits a weight suspended to the arm of the lower Y-shaft to turn the shaft upon its axis, and thereby to open the other valves. The moment previous to the opening these valves the piston had reached the lowest part of its stroke, and the cylinder *above* the piston was filled with steam; but as soon as H is opened, that steam rushes by the eduction-pipe, J, into the condenser, and the cylinder *above* the piston is exhausted. The steam from the boiler entering by I and K acts upon the *lower* side of the piston, and forces it to return to the top of the cylinder. When the piston is very near the upper termination of its stroke, another slider, *a*, raises the handle, and in so doing disengages the catch which permits the upper Y-shaft to revolve upon its own axis, and open the valves G and L, and the downward stroke commences, as has been related. When the piston descends, the buckets, R T, of the air-pump P, and hot-water pump T, also descend." *d*, *f* are the rods and links of the parallel motion, W the governor communicating with the throttle valve L, by means of the lever X. The second air-pump, T, is not used in modern engines, and the sun and planet wheels have given place to the crank; but this engine is as capable of a good performance as the best engines now made.

In the first double-acting engines constructed by Mr. Watt, the motion was imparted from the piston rod to the beam by means of a rack and sector, the upper part of the piston rod being toothed, and working into a toothed arc at the end of the great lever. This plan, however, was found to be objectionable in practice, as the teeth shifted their point of contact to their opposite sides at every turn of the stroke, and the noise and concussion thus occasioned gave rise to injury and inconvenience. To obviate these objections, Mr. Watt contrived a method of connecting the piston rod to the beam by a link and at the same time counteracting the disturbing influence of the beam radius, by means of an expedient termed the parallel motion, for which, and some other improvements, he took out a patent in 1784. This was his fourth patent, his first being for the condensation of the steam in a separate vessel, his second for the production of rotatory motion, and his third for working steam expansively, and for the double action engine. The fourth patent is full of ingenious contrivances, some of which we may here enumerate. The first of them is a new rotatory engine, which might not be unappropriately termed a steam turbine. A vessel shaped like a decanter is divided vertically by a diaphragm, and poised upon a pivot at the bottom, whilst the neck is put in connection with a steam pipe. Each compartment is provided with a valve at the bottom opening inwards, and with valves at the neck, by which the steam may be admitted into each compartment alternately. The vessel is immerged in water up to the neck, by which means both compartments are filled with water, and the steam being then let into one compartment forces out the water through an appropriate aperture at the bottom, and puts the instrument in revolution after the same fashion as a Barker's mill. So soon as the water is expressed out of one compartment, the steam is turned into the other, and that first acted on becomes again full by the rise of the water through the bottom valve, when

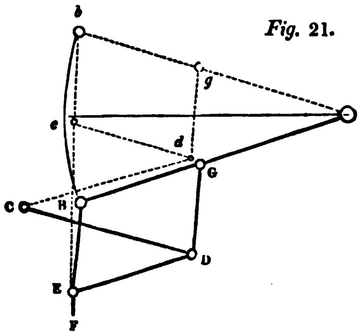
Fig. 20.



the steam pressure is withdrawn, and is thus ready to be again acted upon as at first.

The second contrivance mentioned in this patent is the parallel motion, of which several varieties are represented. Let A B and C D (*fig.* 20.) be two levers situated one above the other in the same vertical plane, and connected by the link B D; during their movement into the position indicated by the dotted lines, the point E will not deviate sensibly out of the vertical line. If, therefore, AB be supposed to be half of the beam of an engine, and the piston rod be attached to the point E, its proper action will be undisturbed by the motion of the end of the beam in the segment of a circle. This kind of parallel motion, however, is not very often employed; but a kind termed the *complete* parallel motion, described in the same specification, is now employed almost universally in the case of land beam engines. Here A B (*fig.* 21.) is half the beam as before, A being the main centre, B E the main links connecting the piston rod, F, with the end of the beam, G D the air-pump links, from the centre of which the air-pump rod is suspended. The rods CD and ED are those which give the parallelism. C D is moveable only round the fixed centre C, but E D is not only moveable round the centre D, but the centre itself moves in the arc described by C D, and by this action E D redresses the distorting influence of its own radius.

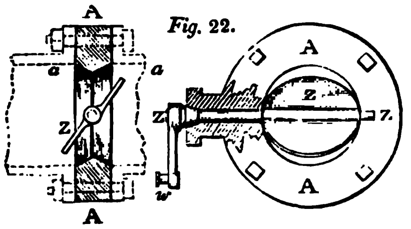
Fig. 21.



The next expedient described in this specification that we shall mention is a method of working a forge hammer by the direct force of steam without the intervention of cams or wheel-work. This contrivance has been of late resuscitated by Mr. Nasmyth of Patricroft, and inventions are continually being propounded as new and improved methods of operation, which are to be found in all their integrity in Mr. Watt's specifications. In his third patent, for example, we have a new variety of engine which is thus described:— "My fifth new improvement consists in making the steam cylinders in the form of greater or lesser segments or sectors of cylindrical vessels; and placing in the centre or axis of the circular curvature of such vessels a round shaft or axle which passes through and extends beyond one or both ends of the steam-vessel, and I shut up the ends of the steam-vessel with smooth flat plates which have proper apertures for the axle or shaft to pass through; and within the steam-vessel I fix to the axle a plate by way of piston, extending from the axle to the circular circumference of the steam-vessel, and also extending from one end of the steam-vessel to the other end thereof, and I make such piston steam-tight by surrounding the parts which fit to the steam-vessel with hemp, or other soft substances, soaked in grease or oil by means of springs made of steel, or other solid and elastic or pliable materials; and within the steam-vessel I fix one or more plates or divisions extending from the axle to the circumference of the steam-vessel; and where these plates or divisions join to or approach to the axle, and also where the said axis passes through the end plates of the steam-vessel, I make such joinings steam or air-tight by similar means." This, in all its main features, is identical with the engine lately projected by Ericson, and fixed by him on board the United States steamer, "Princeton." Again, in one of these patents we have the contrivance known as the trunk engine, which consists of an engine with a hollow piston rod, within which the connecting rod librates. We have also a portable engine and machinery for moving wheel carriages, and it is stated that the steam may either be discharged into the air after having given an impulse to the piston, or partially condensed in vessels exposing a large surface to the atmosphere. Indeed, there is scarce an invention in steam machinery holding out any reasonable advantage that has been propounded since Mr. Watt's time, of which the germ, more or less developed, may not be found in his patents or in his practice.

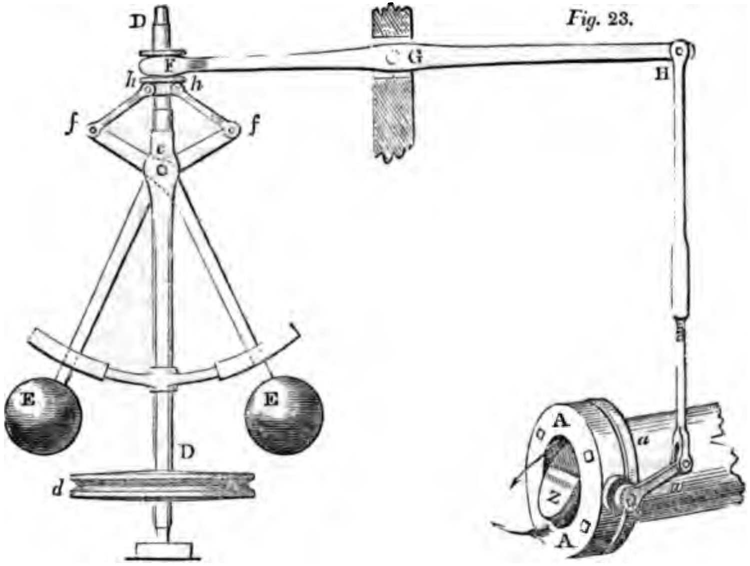
When steam-engines were first employed to turn millwork, it became necessary to employ some expedient to make their movements more regular than they had hitherto been in the performance of their former function of raising water. In his single-acting engines Mr. Watt had been in the habit of using a valve called the throttle-valve, to modify the speed of the piston; and in a case where uniformity of motion was no great consequence, it was sufficient to regulate this valve by hand as occasion required, but in the impulsion of millwork, especially of that description employed in the cotton manufacture, a perfect uniformity in the engine speed became extremely important. This, it was obvious, could only be accomplished by some automatic contrivance, by means of which the engine might be made to redress its own irregularities, and by the application of the governor Mr. Watt perfectly accomplished the desired object. The governor had previously been applied, after a very rude fashion, to the regulation of the motion of windmills, but in its present form it is the creation of Watt, and it has received no improvement since it left his hand. To our less proficient readers a representation of the governor, and an account of the manner of its application to regulate the throttle-valve, may not be unacceptable. A (*fig.* 23.) is the seat of the throttle-valve, and Z the valve itself, turning on a spindle which passes through its centre: *a* is the steam pipe, *w* the throttle-valve lever, on which the rod H proceeding from the governor acts; D D is the spindle of the governor, which is put into revolution by means of a belt acting on the pulley *d;* E E the balls hung on the ends of arms, which cross each other at *e*, like a pair of scissors. On the spindle D D being put into motion, the balls recede from the spindle by virtue of their centrifugal force, and in doing so draw down the collar, into which the lever F works, by means of the links *f, h*. By depressing the end F, of the lever, whose centre is at G, its end H is of course elevated, and the valve Z is thereby partially closed, the effect of which is to redress any extra speed of the engine, which may have caused the balls to diverge beyond their accustomed range.

Fig. 22.



THROTTLE-VALVE.

Fig. 23.



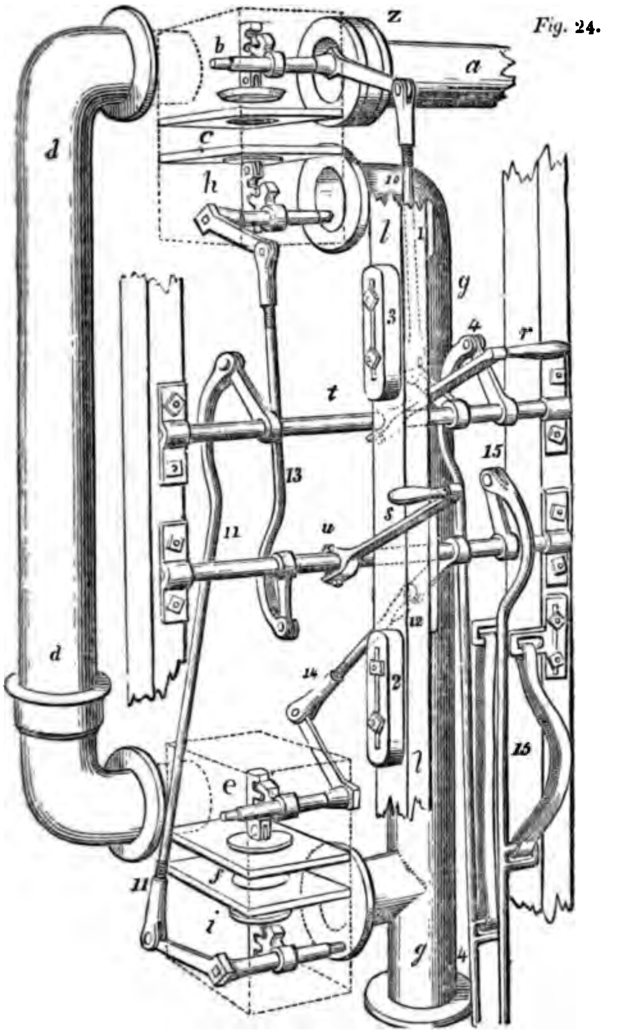
GOVERNOR APPLIED TO THE THROTTLE-VALVE.

The engines erected by Messrs. Boulton and Watt, about 1785, for giving motion to the machinery of the Albion mills, contained all the improvements that we have enumerated, and those engines are the type from which land engines, up to the present time, have been constructed. The sun and planet wheels, indeed, have been discarded in modern engines in favour of the crank, and the main lever is now made of iron instead of wood. The modern valve gearing is also different, and works more harmoniously, the slide valve being used instead of spindle valves moved with tappets; but although the engine is made more elegant by these modifications, it is not made more effectual, and the engines of the Albion mills have been very little exceeded in their performance by the best modern engines, which work with the same measure of expansion.

The valve gearing applied to the engines of the Albion mills, which was that generally employed by Messrs. Boulton and Watt at this time, is worthy of being described. *a d d* (*fig.* 24.) is the steam pipe communicating with the compartments *b* and *e*, above the steam valves. *g g* is the eduction pipe communicating with the spaces *h* and *i*, below the eduction valves. The spaces *c* and *f* communicate with the cylinder.

In the gearing, as represented, the upper steam and under eduction valves are open, so that the piston must be in the act of descending. Z is the throttle-valve, *l* the plug rod, 2 and 3 the tappets, which give motion to the lever *s*, situated on the shaft *u*, and by means of which the upper eduction and lower steam valves are opened and shut through the medium of the rods 13 and 14. The handle *r* on the shaft *t* is moved by tappets on the other side of the plug rod, which are hardly visible in this view, and opens and shuts the upper steam and lower eduction valves at the right intervals by means of the rods 10 and 11. The valves are kept shut by weights suspended from the levers 4 and 15, the levers passing

Fig. 24.

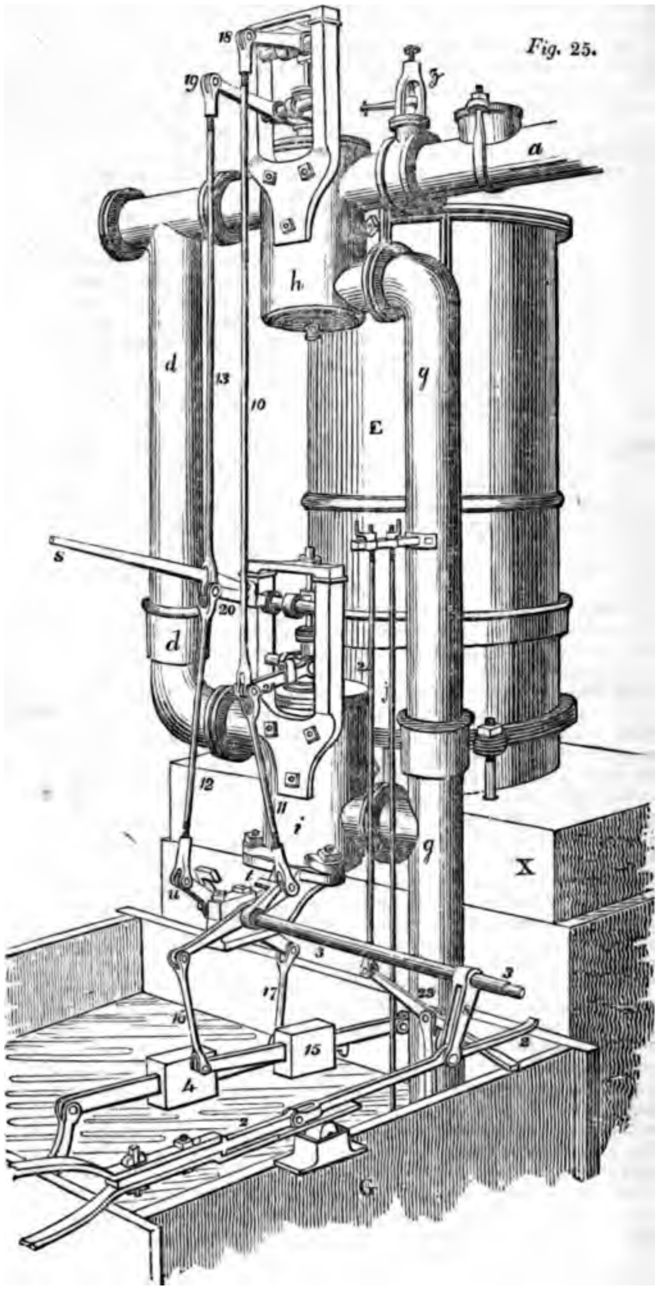


VALVE GEARING OF ONE OF THE ENGINES OF THE ALBION MILLS.

a small distance over the centre, when the valve is closed and the gravity of the weights thus tending to keep the valves closed firmly after the manner of a tumbler. The levers and rods, it will be observed, are in the same straight line when the valves are closed, and it is therefore impossible that the exhausting valves can be forced open by the pressure of the steam. This kind of valve gearing was found to be very effectual so long as it remained in good order; but in the event of wear or mal-adjustment a considerable leakage of steam took place through the eduction valves, and it was therefore found preferable to employ a species of eduction valve that was pressed closer by the steam. Of these improved valves one of the most elegant varieties is that contrived by Mr. Murdoch, of which we here give a representation. *a d d* (*fig.* 25.) is the steam pipe, and Z the throttle-valve, as before; *g g* the eduction pipe, joined to the upper and lower compartments *h* and *i*. The spindles of the eduction valves pass up through the spindles of the steam valves, the eduction valves being connected with the levers 18 and 20, and the steam valves with the levers 19 and 21. Of this valve gearing Mr. Farey has given a very elaborate account, which we here introduce for the benefit of such of our readers as have virtue enough to read it.

"The valves are raised by suitable short levers fixed upon horizontal axes, which are mounted in brackets fixed to the front of each box in which the valves are contained, and rising up above the cover of that box. The spindle of each of the exhausting-valves has a square opening through it near its upper end, to receive the extremity of the lever by which the valve is to be raised; and the hollow spindle of each steam-valve is included between the extremities of two levers, which are affixed upon the same axis parallel to each other, and those extremities enter into a circular groove formed round the outside of the stuffing-box at the top of the hollow spindle, so as to enable those levers to lift up the stuffing-box and the valve. The upper end of the spindles of the exhausting-valves are received in fixed guides which retain 'them in their vertical position, and the lower ends of the same spindles are retained in sockets in the centres of the valve seats. The spindles being thus guided at their upper and lower ends, the valves will rise and fall very correctly into their seats. The steam-valves

Fig. 25.



MURDOCH'S VALVE GEARING.

are guided by the same spindles which pass through them, and also by the stuffing-boxes through which their hollow spindles pass in the centres of the covers. The utmost accuracy is required in the execution of these nossels to make the seats for the two valves exactly concentric with each other, and also with the upper edges of the boxes where the covers are fitted on, and with their stuffing-boxes. The horizontal axes of the levers by which the valves are lifted, have other levers 18, 19, and 20, 21, fixed upon them, and projecting out in an opposite direction in front; the ends of these levers are connected by the upright rods 10 and 13, so as to unite the levers for the upper and lower valves *r*, *s*, in two pairs. The levers 20 and 21 can be prolonged, as shown by the dotted lines in *fig.* 24. by inserting the ends of bars *r* and *s* into sockets formed on the top of each lever; these bars serve as lever handles, and by depressing them the engine-man can open either pair of valves, in order to start or stop the engine. The rod 10 connects the end of the lever 20 for the lower exhausting-valve with the lever 19, of the upper steam-valve, and when the handle is depressed it opens both these valves in order to produce the descending stroke of the piston. The rod 13 unites the lever 21 of the lower steam valve, with the lever 18 of the upper exhausting-valve; and when the handle, *s*, is depressed, it opens both these valves, to make the descending stroke of the piston. The valves tend to shut by their own weight, but that would not be quite sufficient; therefore two rods 11, 12 are jointed to the ends of the levers 20, 21, to connect them with the upper ends *t*, *u*, of two inclined levers *t* 16, and *u* 17, which are poised upon a cylindrical part of a horizontal axis 3, 3, and can turn freely round upon that axis, as a centre of motion; these levers are inclined in opposite directions, and cross each other like the two blades of a pair of scissors. The opposite or lower ends of the inclined levers are connected by links 16, 17, with balance treadles 15, 4, which are levers loaded with weights, tending to draw down the lower ends of the inclined levers so as to cause their upper ends *t*, *u*, to bear upwards; this action is transmitted by the rods 11, 12, and 10, 13, to the outer ends of the several levers of the valves, in order to press down the opposite ends of these levers, which act upon the valves and thus cause the valves to shut down close into their seats, whenever they are allowed to descend. In opening either pair of the valves, whether it is done by a man with the handles *r* or *s*, or by the working-gear of the engine itself, the weight 4 or 15 belonging to that pair of valves must be overcome and raised; and the effort made by the weight to return, tends to close that pair of valves. The working-gear is moved by an excentric circle, which is fixed upon the main axis of the crank; it is a circular ring, with a groove formed round the edge like a pulley; and it has a round hole through it, the centre of which is about six inches out of the centre of the circle. This excentric is fixed fast upon the square axis by four wedge pieces, which are applied upon the four flat sides of the square axis, and the outsides of the pieces are formed convex, so as to fill up the round hole through the excentric; these pieces are driven tight into the excentric, so as to jamb it fast upon the axis, that it cannot slip round upon it. A circular brass ring is applied in the groove round the edge of the excentric; it is made in two semicircles put together, and firmly united by nuts screwed upon bolts, which pass through ears projecting out from each semicircle; these bolts are the extreme ends of the two branches of the compound-rod 2, 2, which conveys the motion of the excentric ring to the working-gear; the two branches are joined together into one rod at the end nearest to the cylinder, but they diverge from each other, so as to include the eccentric ring between the screws which are formed upon the other ends of them; one of those screws being over the top of the ring, and the other beneath the bottom of it. When the axis and the excentric turns round, it will move the rod 2, 2 backwards and forwards through a space of about 12 inches at each revolution. The excentric projects but from the axis on the same side as the crank projects out therefrom; consequently when the crank pin, in moving round in its circle, arrives nearly on a level with the axis, and the piston is near the middle of its stroke, the rod 2 will have been moved by the excentric, to the full limit of its course, and will be setting out on its return. When the crank is nearly in a line with the connecting-rod, and the piston is near the top or bottom of its course, the rod 2 will have arrived at the middle of its course. The end of the compound-rod 2, 2, where the two branches are joined into one rod, rests upon a small roller which is mounted in a box fixed near the edge of the condensing cistern; this roller bears the weight of that end of the rod, and allows it to move backwards and forwards; the end of the rod is prolonged beyond the bearing on the roller, by another short rod which is jointed to it, and which acts on a pin at the lower end of a lever 8, fixed upon the horizontal axis 3, 3, near to one end of it. By this means, at every complete stroke of the piston, the axis 3, 3, is turned backwards and forwards about its own centre line; it is supported in two bearings, one at the extreme end fixed to the side wall, and the other is supported by a bracket, which projects out from beneath the lower box, *i*, of the nossels, and is fastened by three bolts, to ears which project out from the lower part of that box to receive the screws. The inclined levers *t* 16 and *u* 17 are fitted freely upon a cylindrical part of the axis 3, close to each side of the latter bearing. To open the valves, two short levers 22, 23 are fixed fast upon the axis 3, close at the sides of the loose inclined levers *t* 16 and *u* 17; the ends of the short levers are like hooks or claws, which turn sideways over the upper ends, *t* and *u*, of the loose levers, in such manner that when, by the reciprocating motion of the axis 3, either of the claws 22 or 23 is depressed below a certain position, the hooked part of that claw will press upon that lever *t* or *u* which belongs to it, and will force that lever down, so as to lift up and open one pair of valves by the connexion of the rods and levers 11, 20, and 10, 19, or 12, 21, and 13, 18. That pair of valves which is thus opened will be kept open, until the claw 22 or 23 returns, and lets them down again by their own weight, aided by that of the loaded lever 4 or 15; but when the valves are shut, the hook at the end of the claw 22 or 23 rises up, and quits the lever *t* or *u*, which then remains stationary without following the claw. The working gear is so adjusted, that the instant after one of the claws 22 or 23 has allowed one pair of valves to close themselves, and is beginning to quit its inclined lever *t* or *u*, the opposite claw 22 or 23 will come in contact with the other inclined lever, and will begin to open the other pair of valves; for the two levers *t* and *u* being inclined in opposite directions, they are acted upon alternately by the two claws 22 and 23; one pair of valves being opened when they move backwards, and the other pair when they move forwards; but one pair of valves is always closed before the other is opened. When the engine is properly at work the axis 3, 3 is moved continually backwards and forwards by the connexion of its lever 8 with the rod 2 of the excentric; but by lifting up the end piece of that rod, it can be disengaged from the joint pin at the end of the lever 8, because the connection is only made by a notch in the under side of the rod which fits over the joint pin of the lever 8, so as to cause the lever to partake of the motion which is given to the rod, by the ring of the excentric, so long as the end rod rests by its weight upon that joint pin, but if the end rod is raised up, its notch will quit the joint pin of the lever 8, and leave that lever at liberty; in which case the weights 4 or 15 will instantly close that pair of valves, which may be open, unless they are held open by pressing down the handles *r* and *s* by the hand. The end piece of the rod 2 can be lifted up by a lever 23, and screw 24; this lever moves about a fixed centre at the upper end of an iron standard, which rises up from the top of the condenser; one end of the lever 23 extends beneath the extremity of the end piece of the rod 2, and the other end is jointed to a vertical rod 24, the upper end of which is a screw, and is received in a nut fitted into a small bracket, which projects out from the side-pipe *g*. The nut has a handle by which it can be turned round, in order to depress the screw, and raise the other end of the lever, so as to lift up the extremity of the rod which is jointed to the end of the rod 2, and thus disengage that rod from the joint pin of the lever 8. The lever 8 is made double, to receive the rod in the interval between its two sides, and when the extremity is borne up by the lever 23, the rod can move freely backwards and forwards within the double lever 8, without communicating any motion to it. The cylinder, with its piston, cover, and bottom, and its steam case are the same as in Mr. Watt's former engines. The steam case is put together round the cylinder in six pieces, joined together by small screw-bolts; there are three segments to form the circle, and two sets of such segments in height; one set is fastened by a flange at top, to the underside of the flange round the top of the cylinder, and the other set is fastened in a similar manner to the lower flange of the cylinder. The flange of the bottom of the cylinder, and that of the base or false bottom beneath it, which is to contain steam to keep up the heat, are all united by the same bolts which fasten the steam-case by passing through all the four flanges. The large bolts which fasten the cylinder cover, pass through the upper flange of the steam-case, and as many smaller bolts are inserted in the spaces between the other large bolts, they pass through the flanges of the steam-case and of the cylinder, their heads being countersunk into the upper surface of the flange of the cylinder, and the nuts beneath. The lower set of segments of the steam-case are enlarged at their upper edges, to form a circular socket for the reception of the lower edges of the upper set of segments, and the joint is made tight by ramming in hemp with tallow; this joint allows the steam-case to accommodate itself to the effect of the expansion or contraction of the cylinder by the heat. The cover of the cylinder is hollow within, to prevent the transmission of heat. In larger engines the hollow space is filled with steam by a small pipe of communication from the steam-case. The false bottom beneath the cylinder is supplied from the steam-case in the same manner. The steam-case is supplied with steam by a small branch from the steam-pipe with a regulating cock; and there is also a syphon pipe, proceeding from the lowest part of the steam-case, to drain away the water which condenses therein. The condensing apparatus within the cistern G is the same as in all Mr. Watt's engines. The lower end of the eduction pipe *g* is joined by a socket joint to the top of the condenser. The foot valve is in the passage between the bottom of the condenser and the bottom of the air-pump; and the discharge valve, from the top of the air-pump, is within the hot well. The blow-valve to discharge the air from the condenser is fitted at the end of a small pipe, which passes through the side of the condensing cistern G, and the blow-valve is covered with water contained in a small cistern, fixed on the outside of the large cistern G. The condensing cistern is made of wood; but, in most of these engines, when the cistern has become decayed, it has been renewed by a cast iron cistern. The injection is admitted into the condenser through a small sluice-valve, the openingof which is regulated by turning the nut of a screw formed on the upper end of an upright rod *j*, which rises up from that valve. The nut has a handle to turn it round, and is supported in the same bracket as the nut of the screw 24 for disengaging the working gear. The sluice-valve is a square brass plate, the flat surface of which is fitted against a corresponding plate fastened to the outside of the condenser, and having an oblong aperture through it, to admit the water whenever the sluice-valve is drawn up so high by its screw *j*, as to uncover a part of the hole; if the sluice is screwed quite down, it covers and stops the hole entirely. The sluice-valve is retained in its place against the fixed perforated plate by ledges, which are fastened to the latter at each side, so as to form a groove which includes the edges of the valve. The aperture is 1¼ inches wide, by 3 inches high; and when the engine is working properly, the sluice is commonly drawn up, so as to open 1½ inches high, making an aperture of 1⅞ square inches for 36 horse power, for an engine of 31 inch cylinder, and 6 feet stroke. The foundations upon which the engine is fixed are built of solid masonry; a thick wall, X, extends across the house, to form the pier for the cylinder; another wall extends nearly across the house, beneath the centre of the great lever; and from this a wall proceeds to the end of the house, to sustain the bearing for the neck of the main axis of the crank. A horizontal passage, called the tunnel, is left beneath these foundations to give access to the lower ends of the foundation bolts, by which the different parts are held down. The tunnel extends beneath all the length of the building, and it has cross branches to pass beneath the bearings for the main axes. The passage is large enough for a man to pass conveniently through it." This ingenious kind of valve apparatus has since been nearly superseded by the slide valve, an invention that also emanated from Soho, and which is now the almost universal expedient for governing the flow of steam to and from the cylinder. Of the slide valve there are several varieties, but the most common kind, is that which assumes the form of a half cylinder; and which is called the D valve, from the shape of its cross section. The eccentric is now adopted almost universally for moving the valves of rotative engines: Mr. Murdoch was the author of this elegant expedient.

"In summing up Mr. Watt's character as a mechanical inventor," says Mr. Farey, "he will be found to occupy the same supereminent station among that class as the illustrious Newton held among philosophers of a higher order." The comparison is, we think, a just one, but scarcely sufficiently illustrative, as it only repeats to the imagination an almost identical image, and we prefer, therefore, to represent Watt as the Shakspeare of mechanical science, for he owes his greatness to the same high gifts which distinguished the prince of poetry. There is no power for which Watt was more remarkable than an inexhaustible fertility of invention, and invention is the poetry of science, for it springs out of an action of mind more nearly akin to poetic ideality than logical demonstration. Like his great poetical progenitor the untaught mechanist could soar without effort to the giddiest heights of fancy and conjure up wilder visions and more fantastic combinations than those even who seek to catch the popular wonder by the eccentricity of their speculations, and, like *him* too, he could, without pausing in his course, come down from these airy summits to the most vulgar details of ordinary life, and become as practical and worldly as the soberest of those who never knew a throb of enthusiasm, and whom nothing could seduce out of the beaten track of a passionless experience: but the opposite elements were so happily blended in his composition, and his high qualities sat upon him so gracefully, that the most speculative could find no objection against him for want of boldness or ingenuity, nor the most timorous for want of steadiness or circumspection: and he walked abroad in the world of mechanical creation, and selected from its stores the materials best adapted to his combinations—ever able to produce new where none suitable already existed, but with a thrift like that of nature declining to exercise any greater power than was demanded by the exigencies of the occasion. There was no vain passion for novelty, and no design upon the popular admiration in any one of Watt's innovations: he adhered to the existing forms of mechanism so long as it was possible to retain them consistently with the due developement of the great principles of improvement he had marked out, and there are no traces to be found throughout his selection of new devices, of that obliquity of judgment which arises in weaker minds from a partiality for their own creations. Men of genius, Mr. Farey says, have usually an undue partiality for their own ideas—a sort of parental affection which does not allow them to make fair selection from their joint stock of acquired and created ideas. We suspect, however, that this partiality arises from too little genius rather than too much, for there cannot be much partiality felt for ideas which spring up spontaneously in the mind in a rapid and rich luxuriance, and it is only in sterile imaginations that every straggling conception can be thought precious. It is not the fact, therefore, that judgment and invention are antagonistic faculties; but when the imagination is active, and new combinations can be formed with ease, the judgment is left unimpeded by the fondness men acquire for their own devices when they are the produce of many a throe.

But whatever theory may be formed on this subject it is at least certain that the greatest masters of invention have been the least transported with the splendour of their own genius, and have been but little disposed to exaggerate the importance of their creations. Shakspeare, after having written his immortal dramas in the brief space of his early manhood, retired into the obscurity of a provincial town, apparently without the consciousness of having done any thing uncommon; and so easy did all his tasks appear to Watt, and so readily did his imagination suggest to him the most ingenious and profound explanations, that it is hard to reconcile the notion of difficulty with the spectacle of so much facility, and it becomes necessary to compare him with others before we can form a true conception of his merits. To what an exaltation, for example, does he not rise by a comparison with Smeaton!—certainly, next to Watt, the greatest mechanical genius of his time, and one that has not been excelled by any which has appeared since that epoch. He began his improvements upon the steam engine about the same time as Watt, and he accomplished all, perhaps, that could be expected of a patient and technical mind; but the genius of Watt ascended from the narrow circuit of actual experience into the bright fields of imagination, and drew from thence the inspiration that directed its subsequent achievements. Smeaton was able to *improve*, but Watt was able also to *create*; and as he had never received any practical training, his mind was free from the fetters of authority, and the fire of his imagination, unquenched by the chilling dogmas of a sect. Much of his success is, we think, due to the unsettled condition of his early life, which permitted and demanded a wider range of thought than if its exercise had been restricted to a single occupation; and the condition of an humble artizan was much better adapted for the developement of his genius than the ease of academic shades, or the vanities of scholastic discipline. Had Watt been born in the atmosphere of Oxford, he would have subsided, in all probability, into an expounder of the metres of Pindar; or had his imagination been broken in the schools, he would have sunk, in all likelihood, into a mere professor of engineering. It is from the race of artizans that genius is chiefly recruited, for the imaginations of the illiterate can at least have fair play, and their spirits are not quelled by the presence of those idols of perfection, before which the learned bow down in adoration. Homer, Socrates, Shakspeare, Burns, Watt, and almost all great original spirits, have sprung from the condition of humble life, and the splendour of their genius is due in a great measure to that happy accident, for they had thus no precedent constantly before their eyes, within the boundary of which they had to restrain their inspirations, but followed nature without wavering through all her varied aspects, and without suffering any idol to interpose between them and that GREAT LIGHT, of which their own glory is the reflection.

It ought to be needless to guard this language against the supposition that we hold all learning to be useless, or that science can be of no value to the operative engineer; but it is the tendency of such an attainment, we fear, to lead to a neglect of more serious qualifications, and to quench that fire of the imagination in which all invention has its origin. There will be fewer errors committed, no doubt, as mankind become more learned; but there will also be less originality and adventure; and although dulness may be raised to a higher proficiency, we fear that genius will fail to achieve such mighty advances, and will experience greater difficulty in reaching its natural exaltation. It is the tendency, indeed, of all education to redress the unequal dispensations of nature, and while raising up the feeble to cast down the strong and the aspiring. The hot-beds of a college may produce abundant crops of mediocre engineers; but such men as Brindley, Rennie, Telford, and Watt, are not forced into greatness by fictitious heats, but gather strength from the vicissitudes of that rugged region where genius spontaneously unfolds its robust glories, and the practical capacity indigenous to the soil, while cherished by the sunshine, is invigorated by the storm. One cause of Watt's greatness as an engineer is traceable to the fact, that he was not an engineer merely; and this is made so clear by Lord Jeffrey's sketch of the character of Watt, that we shall here introduce his exquisite delineation:—

"Independently of his great attainments in mechanics, Mr. Watt was an extraordinary, and in some respects a wonderful man. Perhaps no individual in his age possessed so much and such varied information, had read so much, or remembered what he read so accurately and well. He had infinite quickness of apprehension, a prodigious memory, and a certain rectifying and methodising power of understanding, which extracted something precious out of all that was presented to it. His stores of miscellaneous knowledge were immense; and yet less astonishing than the command he had at all times over them. It seemed as if every subject that was casually started in conversation with him had been that which he had been last occupied in studying and exhausting: such was the copiousness, the precision, and the admirable clearness of the information which he poured out upon it without effort or hesitation. Nor was this promptitude and compass of knowledge confined in any degree to the studies connected with his ordinary pursuits. That he should have been minutely and extensively skilled in chemistry and the arts, and in most of the branches of physical science, might perhaps have been conjectured; but it could not have been inferred from his usual occupations, and probably is not generally known, that he was curiously learned in many branches of antiquity metaphysics, medicine, and etymology, and perfectly at home in all the details of architecture, music, and law. He was well acquainted, too, with most of the modern languages, and familiar with their most recent literature. Nor was it at all extraordinary to hear the great mechanician and engineer detailing and expounding for hours together the metaphysical theories of the German logicians, or criticising the measures or the matter of German poetry."[*] It was this promiscuous occupation of the mind, and the energy of imagination which flows from such an exercise, which raised Watt so high above all competitors in the career of mechanical improvement; so that during the interval employed by Smeaton in working out a few insignificant improvements, *he* brought to maturity those miracles of inventive power, which have earned the world's admiration, and which the experience and ingenuity of mankind, for the best part of a century, have vainly endeavoured to transcend. In some of the engines indeed, latterly constructed in Cornwall and other places, which work with high-pressure steam expansively, a greater measure of economy in fuel has been attained than Watt ever realized; but that result is not due to the discovery of any new method of operation, but arises merely from the larger application of the great principles Watt marked out than in his time would have consorted with the prejudices of the public. No one knew better than Watt did, that a most important economy was to be gained by carrying the principle of expansion to a higher pitch, and using steam of a higher elasticity than he had yet dared to employ; but he knew as well that the use of steam of a high pressure was not unattended with danger in those days of mechanical inexperience, and he would not risk an accident for the sake of adding to his gains, or heightening the popular astonishment. However far we may proceed in the path of steam improvement, we shall find unequivocal traces of Watt having been there before; and the conceptions which start up in our minds, and which at first sight we believe to be original and important, we shall find on inquiry to have previously suggested themselves to his imagination. The fact appears to be that the track of knowledge chosen by him has been so thoroughly explored, that he has left nothing for his successors to discover; and we do not at present see how any material improvement can now take place in steam-engines except by the introduction of new powers of nature, which the progress of discovery may reveal. The machine may, perhaps, be thrown into still more commodious forms, and greater niceties of workmanship may be lavished upon its construction; but every thing is to be got by Watt's principle of action, that mere fire and water can give, and the next step of improvement must be the employment of cheaper agencies. And though the present steam-engine may pass away as it no doubt will, and cease to have any existence, except in the page of history, Watt's glory will suffer no obscuration, but in the lapse of years must rise to a wider and brighter effulgence. However excellent or extraordinary the new mechanism may be, it will, we believe we may predict, rather be compounded of the ideas of a multitude of minds, than be the product of a single master spirit; and ages must elapse before another such example of intellectual strength as Watt presented can be given to the world, or before nature can be expected to recruit the power necessary to so marvellous a creation.

But it is not merely the invention of all that is admirable in the structure of the modern steam-engine that gives Watt a claim upon the world's admiration. Nearly all the great inventions of the age have had their origin or practical developement at Soho, among which we may enumerate gas lighting, bleaching by chlorine, warming apartments by steam, coining money so as to obviate forgery, the copying press, and many other devices. Lord Stanhope's printing press, again, is a manifest copy of the system of compound levers, contrived by Mr. Watt, for opening the valves of his engines with a small exertion of force, and the machinery with which Fulton accomplished navigation by steam was constructed at Soho, and realised the desired result by the excellence of its performance. In some of these developements, it is true, Watt was not the only person concerned, and Mr. Boulton and Mr. Murdoch must be mentioned with great honour, as much was due to their ingenuity; yet these lesser lights were but the satellites of a system of which *he* was the central sun, and gave out merely the lustre they had derived from the effulgence of *his* genius. It cannot now be ascertained with any precision how far the various admirable contrivances of Murdoch are due to specific communications with Mr. Watt, or what proportion of their excellence they owe to his supervision or suggestion, but it was the light and heat of the master-mind that gave fertility to the disciple's imagination, and that fell upon his spirit like fire from heaven. In the domain of unapplied science, Watt is known for his discovery of the composition of water, — in which he was independent of Cavendish,—for the determination of the bulk of a given weight of steam at different temperatures, and for numerous aids that he lent to pneumatical inquiry; while his direct achievements in the various departments of the arts, stupendous as they are, are less in amount than those which he has indirectly accomplished. The new methods of construction he introduced, and the new resources of art he opened up, have extended, from the manufacture of steam-engines, over the whole face of mechanical industry, and in an inconceivably short time have regenerated arts that had been stationary for ages. The improved mill-gearing, for example, of modern times, the superior cranes, fire-engines, and other mechanisms, the construction of iron ships, and the application of iron to a thousand purposes for which it was before unthought of, from having cheapened the production of the material and facilitated the resources of its workmanship,—these, and a thousand other mighty changes, have flowed from Watt's innovations, for *they* first reconciled great strength with great accuracy of workmanship, and set in striking opposition the barbarous expedients of most of the other arts with the refinements he had invented.

Of Watt's personal character we are unable, from our own knowledge, to say anything, as he had passed from this sublunary scene before our day; but he appears to have won the reverential affection of every one who approached him, and every engineer even now looks upon him as a father. A more remarkable proof, however, of his goodness, is to be found in the undying affection of his son, to whom, throughout a long life, he was the object of fervent adoration. Never before was there such an example of filial love. The worship of his father's memory, and the vindication of his father's fame, has been the sole aim and purpose of the son's being—an absorbing passion, which none but a generous nature could feel, and nothing but perfection inspire.—Upon this subject, however, we happen also to have the testimony of Lord Jeffrey, which we cannot do better than here transcribe:—

"It is needless to say, that, with those vast resources, his conversation was at all times rich and instructive in no ordinary degree: but it was, if possible, still more pleasing than wise, and had all the charms of familiarity, with all the substantial treasures of knowledge. No man could be more social in his spirit, less assuming or fastidious in his manners, or more kind and indulgent towards all who approached him. He rather liked to talk—at least in his latter years: but though he took a considerable share of the conversation, he rarely suggested the topics on which it was to turn, but readily and quietly took up whatever was presented by those around him; and astonished the idle and barren propounders of an ordinary theme, by the treasures which he drew from the mine they had unconsciously opened. He generally seemed, indeed, to have no choice or predilection for one subject of discourse rather than another; but allowed his mind like a great cyclopædia to be opened at any letter his associates might chose to turn up, and only endeavoured to select, from his inexhaustible stores, what might be best adapted to the taste of his present hearers. As to their capacity he gave himself no trouble; and, indeed, such was his singular talent for making all things plain, clear, and intelligible, that scarcely any one could be aware of such a deficiency in his presence. His talk, too, though overflowing with information, had no resemblance to lecturing or solemn discoursing, but on the contrary, was full of colloquial spirit and pleasantry. He had a certain quiet and grave humour, which ran through most of his conversation, and a vein of temperate jocularity, which gave infinite zest and effect to the condensed and inexhaustible information which formed its main staple and characteristic. There was a little air of affected testiness, too, and a tone of pretended rebuke and contradiction, with which he used to address his younger friends, that was always felt by them as an endearing mark of his kindness and familiarity,—and prized accordingly, far beyond all the solemn compliments that ever proceeded from the lips of authority. His voice was deep and powerful,—though he commonly spoke in a low and somewhat monotonous tone, which harmonised admirably with the weight and brevity of his observations; and set off to the greatest advantage the pleasant anecdotes, which he delivered with the same grave brow, and the same calm smile playing soberly on his lips. There was nothing of effort indeed, or impatience, any more than of pride or levity, in his demeanour; and there was a finer expression of reposing strength and mild self-possession in his manner, than we ever recollect to have met with in any other person. He had in his character the utmost abhorrence for all sorts of forwardness, parade, and pretension; and, indeed, never failed to put all such impostures out of countenance, by the manly plainness and honest intrepidity of his language and deportment.

"In his temper and dispositions he was not only kind and affectionate, but generous and considerate of the feelings of all around him; and gave the most liberal assistance and encouragement to all young persons who showed any indications of talent, or applied to him for patronage or advice. His health, which was delicate from his youth upwards, seemed to become firmer as he advanced in years, and he preserved up almost to the last moment of his existence, not only the full command of his extraordinary intellect, but all the alacrity of spirit, and the social gaiety which had illumined his happiest days. His friends in this part of the country never saw him more full of intellectual vigour and colloquial animation,—never more delightful or more instructive,—than in his last visit to Scotland in autumn 1817. Indeed, it was after that time that he applied himself, with all the ardour of early life, to the invention of a machine for mechanically copying all sorts of sculpture and statuary;—and distributed among his friends some of his earliest performances, as the productions of 'a young artist, just entering on his eighty-third year!'"

But we must here close these preliminary remarks, which have drawn out to a greater length than we expected, and which, we fear, have provoked the impatience of the more empirical portion of our readers. We shall have little occasion, however, to repent of our discursiveness, if we succeed in any degree in animating the artizans of this great empire to a course of useful acquisition by the influence of Watt's example, or in touching their spirits with a ray from the urn of his genius. The same path by which he won immortality is open also to them, and although few may be endowed with the high gifts by which he was distinguished, yet there is no one who, by energy and perseverance, and by only giving nature fair play, may not rise to a higher eminence than he had dared to hope for even in his own secret contemplations. One condition, however, of his success is, that he must not suffer his mind to become technical, and if an engineer, he must be content to believe that there are other things in the world worthy of his attention besides cast-iron and steam pressure. He must not coop up his imagination within the narrow limits of a craft, but suffer it to roam over creation in its endless fields of beauty; and must cherish a love for nature and for *human* nature—and hold communion with the spirits of glorious aspect and attractive grace that people the world of fancy, and survey the enchantments wrought by genius in every field of enterprise—yielding his affection not only to those high virtues which dignify humanity, but to those "humbler charities that soothe and bless" like flowers scattered upon the desert. It is only by thus giving full scope to his imagination, and cultivating *all* his capacities, that his mind can preserve its just proportions, or grow to any loftiness of stature. And without imagination there can be no invention, for the imagination is the great discovering power, and can only flourish where there is abundant room given for its exercise. To some of our readers we believe it will appear that all excursions of the fancy must be unavailing, and that science or experience should be their guiding star; but we would warn them against this error, and would give them the example of Watt in confirmation of our hypothesis, who certainly owed his superiority to something nearly akin to poetic inspiration. Facts, of course, there must be derived both from science and from experience, for these are the materials with which the imagination works; but facts of themselves are a mere *caput mortuum*, that encumber as much as they enrich their possessor, and it is only when touched by the fire of the imagination, that they spring into life and fruitfulness. Upon some minds, however, that have not read their lesson aright the example of Watt's greatness has operated rather as a discouragement than a provocative to exertion, for they have been smitten with awe by the majesty of his genius; and their enterprize has been repressed by the contemplation of such hopeless perfection. Their spirits have been overshadowed by his greatness, like the puny saplings that pine beneath the shade of some majestic tree; and their energies have never been invigorated by difficulty, nor by the storms and sunshine of the intellectual world. We therefore find very little of novelty to have originated among well-educated engineers, but almost all great innovations have been the work of some less reverential spirit; and whoever aspires to the work of invention must go *himself* to the fountain of human thought and feeling, and suffer the shadow of no mind to come between him and nature. And if the field in which Watt laboured be exhausted, if his ingenuity has made further improvement upon the present steam-engine in any material point hopeless so long as fire remains the impelling power, there are innumerable other fields of enterprize, yet untrodden to reward the industry of future generations. The resources of electricity and magnetism, of thermo-electricity and of hidden powers of nature perhaps, yet to be revealed, present a boundless prospect for the exercise of human ingenuity. These we commend to the attention of our readers and more particularly to the order of working men; for as it is by the ingenuity of the artizan class that the steam-engine has been brought to its present maturity it is to that class the public looks with expectation for its supercession by something better.

MECHANICAL DEFINITIONS.

Before entering upon the explanation of those elementary principles of mechanics and chemistry, which it is necessary to comprehend before much progress can be made in the study of the steam-engine, we shall set down a few useful tables which we should require to give somewhere, and which will be more convenient for reference if collected here, than if scattered throughout the volume. The first that we give relates to the elasticity of steam at different temperatures — a compilation for which we are indebted to the interesting work by Mr. J. Scott Russell, on steam and steam navigation.

Table of the Pressure of Steam, in Inches of Mercury, at different Temperatures.

I. Temperature, Fahrenheit.	II. Dalton.	III. Ure.	IV. Young.	V. Ivory.	VI. Tredgold.	VII. Southern.	VIII. Robison.	IX. Watt.	X. Frank. Inst.	XI. Diff. Dalt. and Ure's Expts.	XII. Diff. Acad. Inst.	XIII. Diff. Tred. and Dalton.	XIV. Temperature, Fahrenheit.
0°	0.08	...	...	...	...	...	...	...	...	...	...	...	0°
10	0.12	...	...	...	...	...	...	...	...	...	...	...	10
20	0.17	...	0.11	...	...	...	...	...	...	...	...	−.09	20
32	0.26	0.20	0.18	...	0.17	0.16	0.00	...	...	−.06	...	−.10	32
40	0.34	0.25	0.20	...	0.24	0.22	0.10	...	...	−.09	...	−.11	40
50	0.49	0.36	0.36	0.36	0.37	0.33	0.20	...	...	−.13	...	−.10	50
60	0.65	0.52	0.53	...	0.55	0.48	0.35	...	...	−.13	...	−.09	60
70	0.87	0.73	0.75	0.73	0.78	0.68	0.55	0.77	...	−.14	...	−.05	70
80	1.16	1.01	1.05	...	1.11	0.95	0.82	...	...	−.16	...	−.06	80
90	1.59	1.36	1.44	1.36	1.53	1.34	1.18	...	...	−.23	...	−.04	90
100	2.12	1.86	1.95	...	2.08	1.84	1.60	1.55	...	−.24	...	−.00	100
110	2.79	2.45	2.62	2.46	2.79	2.56	2.25	...	...	−.34	...	+.05	110
120	3.63	3.30	3.46	...	3.68	3.46	3.00	...	...	−.33	...	+.10	120
130	4.71	4.37	4.54	4.41	4.81	4.43	3.95	...	...	−.34	...	+.16	130
140	6.05	5.78	5.88	...	6.21	5.75	5.15	5.14	...	−.27	...	...	140
150	7.73	7.53	7.55	7.42	7.94	7.46	6.72	...	...	−.20	...	+.21	150
160	9.79	9.60	9.62	...	10.05	9.52	8.65	8.92	...	−.19	...	+.26	160
170	12.31	12.05	12.14	12.05	12.60	12.14	11.05	11.37	...	−.26	...	+.29	170
180	15.38	15.16	15.23	...	15.67	15.20	14.05	12.73	...	−.28	...	+.29	180
190	18.98	19.00	18.96	18.93	19.00	...	17.85	19.00	...	+.12	...	+.02	190
200	23.51	23.60	23.44	...	23.71	...	22.62	...	...	+.09	...	+.20	200
210	28.82	28.88	28.81	28.81	28.86	...	28.65	...	...	+.07	...	+.04	210
212	30.00	30.00	30.00	30.00	30.00	30.00	30.00	29.40	...	0.00	...	+.00	212
220	35.18	35.54	35.19	...	34.92	...	35.8	33.65	...	−0.36	...	−.26	220
230	44.60	43.10	42.47	42.63	42.00	...	44.5	40. +	...	−1.50	...	−2.13	230
240	53.45	51.70	51.66	...	50.24	...	54.9	49.0	...	−1.75	...	−3.21	240

Table of the Temperature of Steam at different Pressures in Atmospheres.

I. Pressure in Atmospheres.	II. French Acad.	III. Dr. Ure.	IV. Young.	V. Ivory.	VI. Tredgold.	VII. Southern.	VIII. Robison.	IX. Watt.	X. Franklin Institute.	XI. Diff Dr. Ure's Experiments.	XII. Diff. Acad. Inst.	XIII. Diff. Tred. and Dalton.	XIV. Pressure in Atmospheres.
1st At.	212.0°	212°	212°	212°	212°	...	212°	212°	212°	0.00	000.2	0.00°	1st At.
2d At.	250.5	250.0	240.3	249	250. +	250.3 +	...	252.5	250.0	...	−0.5	0. +	2d At.
3d At.	275.2	275.0	271	...	274. +	...	267	...	275.2	...	−0.2	−1. +	3d At.
4th At.	293.7	291.5	288	290	294. +	293.4 +	...	...	291.5	...	−2.2	+1.4	4th At.
5th At.	308.8	304.5	302	...	309. +	...	...	...	304.5	...	−4.3	+3.7	5th At.
6th At.	320.4	315.5	...	...	322. −	...	...	...	315.5	...	−4.9	+4.0	6th At.
7th At.	331.7	325.5	...	...	...	...	...	...	326.5	...	−5.7	...	7th At.
8th At.	342.0	336.0	...	337	342. +	343.6 +	...	...	336.0	...	−6.0	+3.3	8th At.
9th At.	350.0	345	...	...	...	...	...	...	345.0	...	−5.0	...	9th At.
10th At.	358.9	...	...	...	...	...	...	...	352.5	...	−6.4	...	10th At.
11th At.	366.8	...	...	...	...	...	...	...	...	...	...	...	11th At.
12th At.	374.0	...	...	...	372. −	...	...	...	...	...	...	+3.0	12th At.
13th At.	380.6	...	...	...	...	...	...	...	...	...	...	...	13th At.
14th At.	386.9	...	...	...	...	...	...	...	...	...	...	...	14th At.
15th At.	392.8	...	...	...	...	...	...	...	383.8	...	−9.0	...	15th At.
16th At.	398.5	...	...	...	...	...	...	...	...	...	...	...	16th At.
17th At.	403.8	...	...	...	...	...	...	...	...	...	...	...	17th At.
18th At.	408.9	...	...	...	...	...	...	...	...	...	...	...	18th At.
19th At.	413.9	...	...	...	...	...	...	...	...	...	...	...	19th At.
20th At.	418.5	...	...	...	414	...	...	...	405	...	−13.5	+2.3	20th At.
30th At.	457.2	...	...	...	...	...	...	...	...	...	...	...	30th At.
40th At.	466.6	...	...	...	...	...	...	...	...	...	...	...	40th At.
50th At.	510.6	...	...	...	...	...	...	...	...	...	...	...	50th At.

The following **Table** will save a vast deal of trouble in computing the area of pistons, safety-valves, &c.; and we believe requires very little apology for its introduction.

TABLE OF THE AREAS, ETC. OF CIRCLES.

Dia.	Circum.	Area.	Side of equal Square.	Dia.	Circum.	Area.	Side of equal Square.
1 in.	3·1416	.7854	·8862	16 in.	50·265	201·062	14·179
¼	3·9270	1·2271	1·0775	¼	51·051	207·394	14·400
½	4·7124	1·7671	1.3293	½	51·836	213·825	14·622
¾	5·4978	2·4052	1·5508	¾	52·621	220·353	14·843
2 in.	6·2832	3·1416	1·7724	17 in.	53·407	226 980	15·065
¼	7·0686	3·9760	1·9939	¼	54·192	233·705	15·286
½	7·8540	4·9087	2·2155	½	54·978	240·528	15·508
¾	8·6394	5·9395	2·4370	¾	55·763	247·450	15·730
3 in.	9·4248	7·0686	2·6586	18 in.	56·548	254·469	15·951
¼	10·210	8·2957	2·8801	¼	57·334	261·587	16·173
½	10·995	9·6211	3·1017	½	58·119	268·803	16·394
¾	11·781	11·044	3·3232	¾	58·905	276·117	16·616
4 in.	12·566	12·566	3·5448	19 in.	59·690	283·529	16·837
¼	13·351	14·186	3·7663	¼	60·475	291·039	17·060
½	14·137	15·904	3·9880	½	61·261	298·648	17·280
¾	14·922	17·720	4·2095	¾	62·046	306·355	17·502
5 in.	15·708	19·635	4·4310	20 in.	62·832	314·160	17·724
¼	16·493	21·647	4·6525	¼	63·617	322·063	17·945
½	17·278	23·758	4·8741	½	64·402	330·064	18·167
¾	18·064	25·967	5·0956	¾	65·188	338·163	18·388
6 in.	18·849	28·274	5·3172	21 in.	65·793	346·361	18·610
¼	19·635	30·679	5·5388	¼	66·759	354·657	18·831
½	20·420	33·183	5·7603	½	67·544	363·051	19·053
¾	21·205	35·784	5·9819	¾	68·329	371·543	19·274
7 in.	21·991	38·484	6·2034	22 in.	69·115	380·133	19·496
¼	22·776	41·282	6·4350	¼	69·900	388·822	19·718
½	23·562	44·178	6·6465	½	70·686	397·608	19·939
¾	24·347	47·173	6·8681	¾	71·471	406·493	20·161
8 in.	25·132	50·265	7·0897	23 in.	72·256	415·476	20·382
¼	25·918	53·456	7·3112	¼	73·042	424·557	20·604
½	26·703	56·745	7·5328	½	73·827	433·731	20·825
¾	27·489	60·132	7·7544	¾	74·613	443·014	21·047
9 in.	28·274	63·617	7·9760	24 in.	75·398	452·390	21·268
¼	29·059	67·200	8·1974	¼	76·183	461·864	21·490
½	29·845	70·882	8·4190	½	76·969	471·436	21·712
¾	30·630	74·662	8·6406	¾	77·754	481·106	21·933
10 in.	31·416	78·540	8:8620	25 in.	78·540	490·875	22·155
¼	32·201	82·516	9·0836	¼	79·325	500·741	22 376
½	32·986	86·590	9·3051	½	80·110	510·706	22·598
¾	33·772	90·762	9·5267	¾	80·896	520·769	22·819
11 in.	34·557	95·033	9·7482	26 in.	81·681	530·930	23·041
¼	35·343	99·402	9·9698	¼	82·467	541·189	23·062
½	36·128	103·869	10·191	½	83·252	551·547	23·484
¾	36·913	108·434	10·413	¾	84·037	562·002	23·708
12 in.	37·699	113·097	10·634	27 in.	84·823	572·556	23·927
¼	38·484	117·859	10·856	¼	85·608	583·208	24·149
½	39·270	122·718	11·077	½	86·394	593·958	24·370
¾	40·055	127·676	11·299	¾	87·179	604·807	24·592
13 in.	40·840	132·732	11·520	28 in.	87·964	615·753	24·813
¼	41·626	137·886	11·742	¼	88·750	626·798	25·035
½	42·411	143·139	11·963	½	89·535	637·941	25·256
¾	43·197	148·489	12·185	¾	90·321	649·182	25 478
14 in.	43·982	153·938	12·406	29 in.	91·106	660·521	25·699
¼	44·767	159·485	12·628	¼	91·891	671·958	25·921
½	45 553	165·130	12·850	½	92·677	683·494	26·143
¾	46·338	170·873	13·071	¾	93·462	695·128	26·364
15 in.	47·124	176·715	13 293	30 in.	94·248	706·860	26·586
¼	47·909	182 654	13·514	¼	95·033	718·690	26·807
½	48·694	188·692	13·736	½	95·818	730·618	27·029
¾	49·480	194·828	13·957	¾	96·604	742·644	27·250

TABLE OF THE AREAS, ETC. OF CIRCLES.—*continued.*

Dia.	Circum.	Area.	Side of equal Square.
31 in.	97·389	754·769	27·472
¼	98·175	766·992	27·693
½	98·968	779·313	27·915
¾	99·745	791·732	28·136
32 in.	100·531	804·249	28·358
¼	101·316	816·865	28·580
½	102·102	829·578	28·801
¾	102·887	842·390	29·023
33 in.	103·672	855·30	29·244
¼	104·458	868 30	29·466
½	105·243	881·41	29·687
¾	106·029	894·61	29·909
34 in.	106·814	907·92	30·131
¼	107·599	921·32	30·352
½	108·385	934·82	30·574
¾	109·170	948·41	30·795
35 in.	109·956	962·11	31·017
¼	110·741	975·90	31·238
½	111·526	989·80	31·460
¾	112·312	1003·7	31·681
36 in.	113·097	1017·87	31·903
¼	113·883	1032·06	32·124
½	114·668	1046·39	32·346
¾	115·453	1060·73	32·567
37 in.	116·239	1075·21	32·789
¼	117·024	1089·79	33·011
½	117·810	1104·46	33 232
¾	118·595	1119·24	33·454
38 in.	119·380	1134·11	33·675
¼	120·166	1149·08	33·897
½	120·951	1164·15	34·118
¾	121·737	1179·32	34·340
39 in.	122·522	1194·59	34·561
¼	123·307	1209·95	34·783
½	124·093	1225·42	35·005
¾	124·878	1240·98	35·226
40 in.	125·664	1256·64	35·448
½	127·234	1288·25	35·891
41 in.	128·805	1320·25	36·334
½	130·376	1352·65	36·777
42 in.	131·947	1385·44	37·220
½	133·518	1418·62	37·663
43 in.	135·088	1452·20	38 106
½	136·659	1486·17	38·549
44 in.	138·230	1520·53	38·993
½	139·801	1555·28	39·436
45 in.	141·372	1590·43	39·879
½	142·942	1625·97	40·322
46 in.	144·513	1661·90	40·765
½	146·084	1698·23	41·208
47 in.	147·655	1734·94	41·651
½	149·226	1772·05	42·094
48 in.	150·796	1809·56	42·537
½	152·367	1847·45	42·980
49 in.	153·938	1885·74	43·423
½	155·509	1924·42	43·867
50 in.	157·080	1963·50	44·310
½	158·650	2200·96	44·753

Dia.	Circum.	Area.	Side of equal Square.
51 in.	160·221	2042·82	45·196
½	161·792	2083·07	45·639
52 in.	163·363	2123·72	46·082
½	164·934	2164·75	46·525
53 in.	166·504	2206·18	46·968
½	168·075	2248·01	47·411
54 in.	169·646	2290·22	47·854
½	171·217	2332·83	48·298
55 in.	172 788	2375·83	48·741
½	174·358	2419·22	49·184
56 in.	175·929	2463·01	49·627
½	177·500	2507·19	50·070
57 in.	179·071	2551·76	50·513
½	180·642	2596·72	50·956
58 in.	182·212	2642·08	51·399
½	183·783	2687·83	51·842
59 in.	185·354	2733·97	52·285
½	186·925	2780·51	52·729
60 in.	188·496	2827·44	53·172
½	189·066	2874·76	53·615
61 in.	191·637	2922·47	54·048
½	193·208	2970·57	54·501
62 in.	194·779	3019·07	54·944
½	196·350	3067.96	55·387
63 in.	197·920	3117·25	55·830
½	199·491	3166·92	56·273
64 in.	201·062	3216·99	56·716
½	202·633	3267·46	57·159
65 in.	204·204	3318·31	57·603
½	205·774	3369·56	58·046
66 in.	207·345	3421·20	58·489
½	208·916	3473·23	58·932
67 in.	210·487	3525·66	59·375
½	212·058	3578·47	59·818
68 in.	213·628	3631·68	60·261
½	215·199	3685·29	60·704
69 in.	216·770	3739·28	61·147
½	218·341	3793·67	61·591
70 in.	219·912	3848·46	62·034
½	221·482	3903·63	62·477
71 in.	223·053	3959·20	62·920
½	224·624	4015·16	63·363
72 in.	226·195	4071·51	63·806
½	227·766	4128·25	64·249
73 in.	229·336	4185·39	64·692
½	230·907	4242·92	65·135
74 in.	232·478	4300·85	65·578
½	234·049	4359·16	66·022
75 in.	235·620	4417·87	66·465
½	237·190	4476·97	66·908
76 in.	238·761	4536·47	67·351
½	240 332	4596·35	67·794

TABLE OF THE AREAS, ETC. OF CIRCLES — *continued.*

Dia.	Circum.	Area.	Side of equal Square.	Dia.	Circum.	Area.	Side of equal Square.
77 in.	241·903	4656·63	68·237	89 in.	279·602	6221·139	78·874
½	243·474	4717·30	68·680	½	281·173	6291·236	79.317
78 in.	245·044	4778·37	69·123	90 in.	282·743	6361·725	79·760
½	246·615	4839·83	69·566	½	284·314	6432·607	80·204
79 in.	248·186	4901·68	70·009	91 in.	285·885	6503·882	80·647
½	249·757	4963·92	70·453	½	287·456	6575·550	81·090
80 in.	251·328	5026·56	70·896	92 in.	289·027	6647·610	81·533
½	252·898	5089·58	71·339	½	290·597	6720·063	81·976
81 in.	254·469	5153·00	71·782	93 in.	292·168	6792·909	82·419
½	256·040	5216·82	72·225	½	293·739	6866·147	82·862
82 in.	257·611	5281·02	72·668	94 in.	295·310	6939·778	83·305
½	259·182	5345·62	73·111	½	296·881	7013·802	83·748
83 in.	260·752	5410·62	73·554	95 in.	298·451	7088·218	84·192
½	262·323	5476·00	73·997	½	300·022	7163·028	84·635
84 in.	263·894	5541·78	74·440	96 in.	301·593	7238·229	85·078
½	265·465	5607·95	74·884	½	303·164	7313·824	85·521
85 in.	267·036	5674·51	75·327	97 in.	304·734	7389·811	85·964
½	268·606	5741·47	75·770	½	306·305	7466·191	86·407
86 in.	270·177	5808·81	76·213	98 in.	307·876	7542·964	86 850
½	271·748	5876·55	76·656	½	309·447	7620·129	87·293
87 in.	273·319	5944·69	77·099	99 in.	311·018	7697·687	87·736
½	274·890	6013·21	77·542	½	312·588	7775·638	88·180
88 in.	276·460	6082·13	77·985	100 in.	314·159	7854·982	88·623
½	278·031	6151·44	78·428				

TABLE OF THE EXPANSION OF AIR BY HEAT.

Fahren.		Fahren.		Fahren.	
32	1000	61	1069	90	1132
33	1002	62	1071	91	1134
34	1004	63	1073	92	1136
35	1007	64	1075	93	1138
36	1009	65	1077	94	1140
37	1012	66	1030	95	1142
38	1015	67	1080	96	1144
39	1018	68	1034	97	1146
40	1021	69	1087	98	1148
41	1023	70	1089	99	1150
42	1025	71	1091	100	1152
43	1027	72	1093	110	1173
44	1030	73	1095	120	1194
45	1032	74	1097	130	1215
46	1034	75	1099	140	1235
47	1036	76	1101	150	1255
48	1038	77	1104	160	1275
49	1040	78	1106	170	1295
50	1043	79	1108	180	1315
51	1045	80	1110	190	1334
52	1047	81	1112	200	1364
53	1050	82	1114	210	1372
54	1052	83	1116	212	1376
55	1055	84	1118	302	1558
56	1057	85	1121	392	1739
57	1059	86	1123	482	1919
58	1062	87	1125	572	2098
59	1064	88	1128	680	2312
60	1066	89	1130		

The use of hyperbolic logarithms is indispensable to the computation of the exact power of an engine working expansively; and as tables of such logarithms are rarely in the possession of practical men, we here give such an assortment as will suffice for the uses of the engineer.

TABLE OF HYPERBOLIC LOGARITHMS.

Numb.	Hyp. Log.	Numb.	Hyp. Log.	Numb.	Hyp. Log.	Numb.	Hyp. Log.	Numb.	Hyp. Log.
1·05	.049	3·05	1·115	5·05	1·619	7·05	1·953	9·05	2·203
1·1	·095	3·1	1·131	5·1	1·629	7.1	1·960	9.1	2·208
1·15	·140	3·15	1·147	5·15	1·639	7.15	1·967	9·15	2·214
1·2	·182	3·2	1·163	5·2	1·649	7.2	1·974	9.2	2·219
1·25	·223	3·25	1·179	5·25	1·658	7·25	1·981	9·25	2·225
1·3	·262	3·3	1·194	5·3	1.668	7.3	1·988	9·3	2·230
1·35	·300	3·35	1·209	5·35	1·677	7·35	1·995	9·35	2·235
1·4	·336	3·4	1·224	5·4	1·686	7·4	2·001	9·4	2·241
1·45	·372	3·45	1·238	5·45	1·696	7·45	2·008	9·45	2·246
1·5	·405	3·5	1·253	5·5	1·705	7·5	2·015	9·5	2·251
1·55	·438	3·55	1·267	5·55	1·714	7·55	2·022	9·55	2·257
1.6	·470	3·6	1·281	5·6	1·723	7·6	2·028	9·6	2·262
1·65	·500	3·65	1·295	5·65	1.732	7·65	2·035	9·65	2·267
1·7	·531	3·7	1·308	5·7	1·740	7·7	2.041	9·7	2·272
1·75	·560	3·75	1·322	5·75	1·749	7·75	2·048	9·75	2·277
1·8	·588	3·8	1·335	5·8	1·758	7·8	2·054	9·8	2·282
1·85	·615	3·85	1·348	5·85	1·766	7·85	2·061	9·85	2·287
1·9	·642	3·9	1·361	5·9	1·775	7·9	2·067	9·9	2·293
1·95	·668	3·95	1·374	5·95	1·783	7·95	2·073	9·95	2·298
2·0	·693	4·0	1·386	6·0	1·792	8·0	2·079	10·	2·303
2·05	·718	4·05	1·399	6·05	1·800	8·05	2·086	15	2·708
2·1	·742	4·1	1·411	6·1	1·808	8·1	2·092	20	2·996
2·15	.765	4·15	1·423	6·15	1·816	8·15	2·098	25	3.219
2·2	·788	4·2	1·435	6·2	1·824	8·2	2·104	30	3·401
2·25	·811	4·25	1·447	6·25	1·833	8·25	2·110	35	3·555
2·3	·833	4·3	1·459	6·3	1·841	8·3	2·116	40	3·689
2·35	·854	4·35	1·470	6·35	1·848	8·35	2·122	45	3·807
2·4	·875	4·4	1·482	6·4	1·856	8·4	2·128	50	3.912
2·45	.896	4·45	1·493	6·45	1·864	8·45	2·134	55	4.007
2.5	·916	4·5	1·504	6·5	1·872	8·5	2·140	60	4·094
2·55	·936	4·55	1·515	6·55	1·879	8·55	2·146	65	4·174
2·6	·956	4·6	1·526	6·6	1·887	8·6	2·152	70	4·248
2·65	·975	4·65	1·537	6·65	1·895	8·65	2·158	75	4·317
2·7	·993	4·7	1·548	6·7	1.902	8·7	2·163	80	4·382
2·75	1·012	4·75	1·558	6·75	1·910	8·75	2·169	85	4·443
2·8	1·030	4·8	1·569	6·8	1·917	8·8	2·175	90	4·500
2·85	1·047	4·85	1·579	6·85	1·924	8·85	2·180	95	4·554
2·9	1·065	4·9	1·589	6·9	1·931	8·9	2·186	100	4·605
2·95	1·082	4·95	1·599	·956	1·939	8·95	2·192	1000	6·908
3·0	1·099	5·0	1·609	7.0	1·946	9·0	2·197	10,000	9·210

STRENGTH OF MATERIALS.

The chief materials, of which it is necessary to record the strength in a treatise on the steam engine, are cast and malleable iron; and many experiments have been made at different times upon each of these substances, though not with any very close correspondence. Professor Barlow has made a large number of experiments upon iron of all kinds, and the following is a summary of them:—

Materials.	C	S	E	M
Iron, cast { from - - -	16300 }	8100	69120000	5530000
to - - -	36000 }			
—— Malleable - - -	60000	9000	91440000	6770000
—— Wire - - - -	80000			

The first column of figures, marked C, contains the mean strength of cohesion on an inch section of the material; the second, marked S, the constant for transverse strains; the third, marked E, the constant for deflections; and the fourth, marked M, the modulus of elasticity. The introduction of the hot blast iron brought with it the impression that it was less strong than that previously in use, and the experiments which had previously been confided in as giving results near enough the truth, for all practical purposes, were no longer considered to be applicable to the new state of things. New experiments were therefore deemed necessary, and public spirited persons were not wanting to answer the call; but of all these later trials the results obtained by Mr. Fairbairn and Mr. Eaton Hodgkinson of Manchester appear to be the most entitled to confidence, as great care and labour were spent upon those experiments, and we know them to have been conducted by skilful persons. The following table has been furnished to us by Mr. Fairbairn, and gives, we have no doubt, results as nearly correct as can be required or attained:—

RESULTS OF EXPERIMENTS ON THE STRENGTH AND OTHER PROPERTIES OF CAST IRON, FROM THE PRINCIPAL IRON WORKS IN THE UNITED KINGDOM, BY W. FAIRBAIRN.

In the following Table each bar is reduced to exactly one inch square; and the transverse strength, which may be taken as a criterion of the value of each Iron, is obtained from a mean between the Experiments upon it, given in the Memoirs; — first on bars 4 ft. 6 in. between the supports; and next on those of half the length, or 2 ft. 3 in. between the supports. All the other results are deduced from the 4 ft. 6 in. bars. In all cases the weights were laid on the middle of the bar.

Number of Iron in the scale of strength.	Names of Irons.	Number of Experiments on each.	Specific Gravity.	Modulus of elasticity in lbs. per sq. inch, or stiffness.†	Breaking weight in lbs. of bars 4 ft. 6 in. between supports.	Breaking weight in lbs. of bars 2 ft. 3 in. reduced to 4 ft. 6 in. between supports.	Mean breaking weight in lbs. (S.)	Ultimate deflection of 4 ft. 6 in. bars, in parts of an inch.	Power of the 4 ft. 6 in. bars to resist impact.	Colour.	Quality.
1	Ponkey, No. 3. Cold Blast	4	7.122	17211000	567	595	581	1.747	992	Whitish grey	Hard.
2	Devon, No. 3. Hot Blast *	2	7.251	22473650	537	—	537	1.09	589	White	Hard.
3	Oldberry, No. 3. Hot Blast	5	7.300	22733400	543	517	530	1.005	549	White	Hard.
4	Carron, No. 3. Hot Blast *	2	7.056	17873100	520	534	527	1.365	710	Whitish grey	Hard.
5	Beaufort, No. 3. Hot Blast	5	7.069	16802000	505	529	517	1.599	807	Dullish grey	Hard.
6	Butterley	4	7.038	15379500	489	515	502	1.815	889	Dark grey	Soft.
7	Bute, No. 1. Cold Blast	4	7.066	15163000	495	487	491	1.764	872	Bluish grey	Soft.
8	Wind Mill End, No. 2. Cold Blast	4	7.071	16490000	483	495	489	1.581	765	Dark grey	Hard.
9	Old Park, No. 2. Cold Blast	5	7.049	14607000	441	529	485	1.621	718	Grey	Soft.
10	Beaufort, No. 2. Hot Blast	4	7.108	16301000	478	470	474	1.512	729	Dull grey	Hard.
11	Low Moor, No. 2. Cold Blast	4	7.055	14509500	462	483	472	1.852	855	Dark grey	Soft.
12	Buffery, No. 1. Cold Blast *	5	7.079	15381200	463	—	463	1.55	721	Grey	Rather hard.
13	Brimbo, No. 2. Cold Blast	5	7.017	14911666	466	453	459	1.748	815	Light grey	Rather hard
14	Apedale, No. 2. Hot Blast	3	7.017	14852000	457	455	456	1.730	791	Light grey	Stiff.
15	Oldberry, No. 2. Cold Blast	4	7.059	14307500	453	457	455	1.811	822	Dark grey	Rather soft.
16	Pentwyn, No. 2.	4	7.038	15193000	438	473	455	1.484	650	Bluish grey	Hard.
17	Maesteg, No. 2.	5	7.038	13959500	453	455	454	1.957	886	Dark grey	Rather soft.
18	Muirkirk, No. 1. Cold Blast *	4	7.113	14003550	443	464	453	1.734	770	Bright grey	Fluid.
19	Adelphi, No. 2. Cold Blast	5	7.080	13815500	441	457	449	1.759	777	Light grey	Soft.
20	Blania, No. 3. Cold Blast	5	7.159	14281466	433	464	448	1.726	747	Bright grey	Hard.
21	Devon, No. 3. Cold Blast *	4	7.285	22907700	448	—	448	.790	353	Light grey	Hard.
22	Gartsherrie, No. 3. Hot Blast	5	7.017	13894000	427	467	447	1.557	998	Light grey	Soft.
23	Frood, No. 2. Cold Blast	5	7.031	13112666	460	434	447	1.825	841	Light grey	Open.
24	Lane End, No. 2.	3	7.028	15787666	444	—	444	1.414	629	Dark grey	Soft.
25	Carron, No. 3. Cold Blast *	5	7.094	16246966	444	443	443	1.336	593	Grey	Soft.
26	Dundyvan, No. 3. Cold Blast	4	7.087	16534000	456	430	443	1.469	674	Dull grey	Rather soft.
27	Maesteg (Marked Red)	5	7.038	13971500	440	444	442	1.887	830	Bluish grey	Fluid.
28	Corbyns Hall, No. 2.	5	7.007	13845866	430	454	442	1.687	727	Grey	Soft.
29	Pontypool, No. 2.	5	7.080	13136500	439	441	440	1.857	816	Dull blue	Rather soft.
30	Wallbrook, No. 3.	5	6.979	15394766	432	449	440	1.443	625	Light grey	Rather hard.
31	Milton, No. 3. Hot Blast	4	7.051	15852500	427	449	438	1.368	585	Grey	Rather hard.
32	Buffery, No. 1. Hot Blast *	3	6.998	13730500	436	—	436	1.64	721	Dull grey	Soft.
33	Level, No. 1. Hot Blast	5	7.080	15452500	461	403	432	1.516	699	Light grey	Soft.
34	Pant, No. 2.	5	6.975	15280900	408	455	431	1.251	511	Light grey	Rather hard.
35	Level, No. 2. Hot Blast	6	7.031	15241000	419	439	429	1.358	570	Dull grey	Soft.
36	W. S. S., No. 2.	5	7.041	14953333	413	446	429	1.339	554	Light grey	Soft.
37	Eagle Foundry, No. 2. Hot Blast	4	7.038	14211000	408	446	427	1.512	618	Bluish grey	Soft.
38	Elsicar, No. 2. Cold Blast	4	6.928	12586500	446	408	427	2.224	992	Grey	Soft.
39	Varteg, No. 2. Hot Blast	4	7.007	15012000	422	430	426	1.450	621	Grey	Hard.
40	Coltham, No. 1. Hot Blast	5	7.128	15510066	464	385	424	1.532	716	Whitish grey	Rather soft.
41	Carroll, No. 2. Cold Blast	4	7.069	17036000	430	408	419	1.231	530	Grey	Hard.
42	Muirkirk, No. 1. Hot Blast *	4	6.953	13294400	417	419	418	1.570	656	Bluish grey	Soft.
43	Bierley, No. 2.	5	7.185	16156133	404	432	418	1.222	494	Dark grey	Soft.
44	Coed-Talon, No. 2. Hot Blast *	4	6.969	14322500	409	424	416	1.882	771	Bright grey	Soft.
45	Coed-Talon, No. 2. Cold Blast *	5	6.955	14304000	408	418	413	1.470	600	Grey	Rather soft.
46	Monkland, No. 2. Hot Blast	3	6.916	12259500	402	404	403	1.762	709	Bluish grey	Soft.
47	Ley's Works, No. 1. Hot Blast	3	6.957	11539333	392	—	392	1.890	742	Bluish grey	Soft.
48	Milton, No. 1. Hot Blast	4	6.976	11974500	353	386	369	1.525	538	Grey	Soft and fluid.
49	Plaskynaston, No. 2. Hot Blast	5	6.916	13341633	378	337	357	1.366	517	Light grey	Rather soft.

The irons with asterisks are taken from the Experiments on Hot and Cold Blast Iron, made by Mr. Fairbairn and Mr. Hodgkinson for the British Association for the Advancement of Science. — See Seventh Report, Volume VI.

† The modulus of elasticity was usually taken from the deflection caused by 112 lbs. on the 4 ft. 6 in. bars.

RULE.

To find from the above table the breaking weight in rectangular bars, generally. Calling b and d the breadth and depth in inches, and l the distance between the supports, in feet, and putting 4.5 for 4 ft. 6 in., we have $\frac{4.5 \times b d^2 S}{l}$ = breaking weight in lbs.,—the value of S being taken from the Table above.

For example: What weight would be necessary to break a bar of Low Moor Iron, 2 inches broad, 3 inches deep, and 6 feet between the supports? According to the rule given above, we have $b = 2$ inches, $d = 3$ inches, $l = 6$ feet, $S = 472$ from the Table. Then $\frac{4.5 \times b d^2 S}{l} = \frac{4.5 \times 2 \times 3^2 \times 472}{6} = 6372$ lbs. = the breaking weight.

TABLE OF THE COHESIVE POWER OF BODIES WHOSE CROSS SECTIONAL AREAS EQUAL ONE SQUARE INCH.

METALS.	Cohesive Power, in lbs.	Cohesive Power, in Tons.
Swedish bar iron - - - -	65,000	29·20
Russian do. - - - - -	59,470	26·70
English do. - - - - -	56,000	25·00
Cast steel - - - - - -	134,256	59·93
Blistered do. - - - - -	133,152	59·43
Shear do. - - - - - -	127,632	56·97
Wrought copper - - - -	33,892	15·08
Hard gun metal - - - -	36,368	16·23
Cast copper - - - - -	19,072	8·51
Yellow brass, cast - - - -	17,968	8·01
Cast iron - - - - -	17,628	7·87
Tin, cast - - - - -	4,736	2·11
Bismuth, cast - - - - -	3,250	1·45
Lead, cast - - - - -	1,824	0·81
Elastic power or direct tension of wrought iron, medium quality - - - -	22,400	10·00

NOTE. — A bar of iron is extended ·000096, or nearly one ten-thousandth part of its length, for every ton of direct strain per square inch of sectional area.

DEFINITIONS AND PROPERTIES OF MATTER.

MECHANICS is a science which treats in general of the action of bodies on one another, as regards their motions, their forces, and their velocities. By the laws of mechanics we are taught how to move a given weight with a given power, and how to contrive engines to raise great loads and perform motions however complicated.

Body is the mass or quantity of matter contained in any material substance, and it is always taken as being proportional to the weight or gravity, whatever the figure of the body may be. Body possesses bulk or volume, which signifies the space that is occupied by it: this element must therefore be determined by combining the three dimensions of length, breadth and depth. Weight or gravity is that property in a body by which it endeavours to fall downwards and gain the lowest place; it is called absolute gravity when the body descends in free space, and relative gravity when it descends in a fluid. Specific gravity is the proportion or relation of the weights of different bodies of equal magnitudes, bulks or volume, and is therefore proportional to the density of the bodies. Density is the proportional weight or quantity of matter in a body; so that in two cubes or globes of equal bulk or magnitude, if the one weigh one ounce, pound or cwt. and the other two ounces, pounds or cwts., the density of the latter will be double that of the former; and if it weighs three ounces, &c., its density will be triple, and so on. Rarity is the reverse of density, and is generally understood by referring to the space which is occupied by a given weight of any aëriform substance: thus we say that air is 820 times rarer than water, because an ounce or a pound of air occupies 820 times the space that is occupied by an ounce or a pound of water.

Bodies are either hard, soft, or elastic, and they are also either solid or fluid. A hard body is that which retains its figure unaltered under every circumstance, refusing to yield to any force whatever. A soft body is that which admits its form to be altered, its parts yielding to the least stroke or impression, the body retaining any form that is given to it. An elastic body is that whose parts yield to any stroke or impression, however slight, but which instantly restore themselves when the disturbing agency is removed. A solid body is that whose parts are not easily moved among themselves, and which retains any form that is given to it. A fluid body is that whose parts yield to the slightest impression, being easily moved among themselves in every direction, and the surface when in a state of quiescence is always observed to coincide with a smooth horizontal plane.

PROPERTIES OF MATTER.

The masses or quantities of matter in all bodies are in the compound ratio of their magnitudes and densities; that is, the masses are proportional to the magnitudes multiplied by the densities. This is obvious from the definitions, for in bodies of equal magnitudes the quantities of matter are proportional to the densities; but if the densities are the same, the masses are proportional to the magnitudes; that is, a double magnitude contains a double quantity of matter, a triple magnitude a triple quantity, and so on; consequently, the quantities of matter are in the ratio compounded of the magnitudes and densities. In similar bodies the masses or quantities of matter, are proportional to the densities and cubes or third powers of the diameters; that is, the quantities are proportional to the densities multiplied by the cubes of the diameters, for the magnitudes of bodies are as the cubes of their diameters, or the cubes of their like linear dimensions. The quantities of matter in all bodies, are in the compound ratio of the magnitudes and specific gravities; that is, the quantities of matter are proportional to the magnitudes of the bodies multiplied by the specific gravities, the densities and specific gravities being proportional. From the principles here stated we deduce the following particulars in regard to the properties of matter.

The quantity of matter in bodies is proportional to the magnitudes multiplied by the densities or specific gravities, or the quantity of matter is proportional to the cube of the diameter multiplied by the density or specific gravity. The magnitude of a body is proportional to the quantity of matter which it contains divided by the density or specific gravity, or the magnitude is proportional to the cube of the diameter, or the cube of any linear dimension. The density of a body is proportional to the quantity of matter divided by the magnitude, or it is proportional to the specific gravity. From these few particulars we obtain the solutions of the following questions in reference to the properties of matter.

EXAMPLE. Let the magnitudes of two bodies be 256 and 108 cubic inches respectively, and their densities or specific gravities as 2 to 3; it is required to determine the proportional quantities of matter in the two bodies. The method of resolving this example is perfectly manifest from what precedes, for we have stated that the quantities of matter are proportional to the magnitudes multiplied by the densities, hence it is

$$256 \times 2 : 108 \times 3 :: 1 : \frac{81}{128} = 0{\cdot}6328,$$

so that the quantities of matter in the two bodies are to each other as 1 to 0·6328 very nearly.

To vary the question, let it be proposed to determine the proportional magnitudes of the two bodies, their proportional densities being as 2 to 3, and the quantities of matter as 1 to 0·6328, or as 1 to $\frac{81}{128}$. We have stated above, that the magnitudes of bodies are proportional to the quantity of matter divided by the density; hence we have

$$\frac{1}{2} : \frac{0{\cdot}6328}{3} :: 1 : 0{\cdot}4219 \text{ very nearly.}$$

Consequently the proportional magnitudes are as 1 to 0·4219 nearly, or accurately as 64 to 27; it therefore follows, that if one magnitude be given the other can readily be found; thus, for instance, if the greater magnitude be 256 cubic inches, the lesser will be 108 cubic inches, for 64 : 27 :: 256 : 108.

GENERAL LAWS OF MOTION AND FORCES.

Motion is a continual and successive change of place: if the body moves equally, it is called *equable* or uniform motion; but if the motion increases or decreases, it is called *accelerated* or *retarded motion*, and, when it is compared with some other body at rest, it is called *absolute motion*, but when compared with other bodies in motion, it is called *relative motion*. The direction of motion is the way the body tends or the line in which it moves, and the *quantity of motion* is the motion a body has when considered with regard to the quantity of matter and velocity conjointly. This is also called the *momentum* or *mechanical* effect.

Velocity is an affection of motion by which a body is carried over a certain space in a certain time, and is greater or less, according as the body is carried over a greater or less space in a certain specified time, as a second or a minute. The measure of velocity is the space or distance through which a body moves uniformly in a determinate portion of time; thus we say the piston of a steam-engine travels with a velocity of 220 feet per minute, and a cannon ball with the velocity of 1600 feet per second. The variations which we have attributed to motion are peculiar also to velocity, but they need not be repeated.

Force is a power exerted on a body to put it in motion or to stop it when it is in motion, and it admits of two varieties; namely, permanent, and impulsive or percussive forces. A permanent force is that which acts constantly with the same intensity, such as pressure or the force of gravity. But if it act instantaneously, or but for an imperceptibly short space of time, it is known by the name of impulse or percussion. Forces are also distinguished into motive and accelerating or retarding forces. A motive or moving force is the power of an agent to produce motion, whether it be by pressure or by impact, and it is equal or proportional to the momentum which it generates in the moving body. An accelerating or retarding force is generally understood to be that which influences or affects the velocity only, or it is that by which the velocity is increased or decreased, and it is always equal or proportional to the motive force directly, and to the mass or body moved inversely; that is, it is either equal or proportional to the motive force divided by the weight of the body moved.

In addition to the above definitions, there are several axioms or first principles on which Sir Isaac Newton founded the doctrine of mechanical science, and by which he was led through a train of beautiful but recondite inquiry to the discovery of those simple and immutable laws that were established for the government of the universe. The axioms or laws of motion alluded to are as follows.

AXIOM OR LAW 1. *All bodies endeavour to persevere in or maintain their present state, whether they be at rest or moving uniformly in a straight line; and in that state they for ever continue, unless they are compelled to alter it by the action of some extraneous force.* This is the law of inertiæ.

AXIOM OR LAW 2. *The change or alteration of motion produced by the action of any external force is always proportional to that force, and the change takes place in the direction of the line in which it acts.* This is the law of perturbation.

AXIOM OR LAW 3. *The action and reaction that take place between any two bodies are always equal and in contrary directions*; that is, by action and reaction equal changes of motion are produced in bodies acting on each other, and these changes take place in contrary directions. This is the law of action and reaction, or the law of reciprocal influences. And from these axioms or laws, in combination with the preceding definitions, Sir Isaac Newton deduces the following theory of motion and forces, which is now universally received.

The momentum or quantity of motion generated by any momentary or impulsive force is directly proportional to the force that generates it. What is here stated is perceived almost intuitively, for every effect is proportional to its adequate cause; so that a double force will produce a double momentum or quantity of motion, and a quadruple force will produce a quadruple momentum, and so on; that is, the motion communicated is always proportional to the communicating force. When bodies are put in motion by the action of any force, the momenta or quantities of motion generated therein are directly proportional to the masses or quantities of matter multiplied by the velocities. This is evident, for if the velocities are equal, the momenta are proportional to the masses, a double mass impinging with a double force, a triple mass with a triple force, and so on. And in like manner, when the masses are the same, a double velocity requires a double force to produce it, and a triple velocity a triple force; or, in other words, the velocity is proportional to the motive force. But as we have stated above, the momentum or quantity of motion is proportional to the force that produces it; and, consequently, when the mass is the same, the momentum is proportional to the velocity; therefore, when neither the mass nor velocity is the same, the momentum is proportional to their product.

When the motions are uniform, the spaces or distances described or passed over by the moving bodies are directly proportional to the velocities multiplied by the times of their description. In uniform motions, the time occupied by the motion is proportional to the space described divided by the velocity. But when the velocity is constant, the space is proportional to the time, and when the space is given, the time is inversely as the velocity; that is, a greater velocity requires less time to carry it over the same space. Again, in uniform motions, the velocity is proportional to the space divided by the time; hence it follows, that when the time is constant, the velocity is proportional to the space described, and when the space is constant, the velocity is inversely as the time of description.

By attentively considering the principles just enunciated, it will readily be perceived that the following general analogies may be deduced from them, and by means of these analogies may be resolved all the questions that can arise in reference to uniform motions, and to the effects of momentary or impulsive forces.

1. The momentum or quantity of motion is directly proportional to the generating force.
2. The momentum is directly proportional to the body or quantity of matter moved, multiplied by the velocity.
3. The space passed over in any time is directly proportional to the time multiplied by the velocity.

These general theorems, concise as they are, embody a vast fund of useful information in regard to mechanical science, and in order to render their application as clear and intelligible as possible, we shall resolve a few questions by way of illustration.

Example 1. Suppose that one body contains 25 times the matter that another body contains, and let the lesser body move 1000 times faster than the greater body; what will be the relation or proportion of their momenta?

Here it will be instantly perceived, that the solution of the question depends on the second of the general analogies given above, for in that the data and incognito of the question are involved; the proportional quantities of matter and proportional velocities are given, and the proportional momenta required; the process indicated is therefore as follows, viz.: As the greater body multiplied into its velocity, is to the lesser body multiplied into its velocity, so is the momentum of the greater body, to that of the lesser body.

$$25 \times 1 : 1 \times 1000 :: 1 : 40.$$

It therefore appears that the lesser body must move with a force 40 times greater than the greater body, or, in other words, the momenta are as 1 to 40.

Example 2. Suppose a body of 20 lbs. weight to be impelled by such a force as will carry it through a space of 100 feet in one second of time, with what velocity would a body of 8 lbs. weight move if it were urged by the same force?

In this example we are to consider the momentum as being the same in both bodies, in which case, that term in the second analogy will be denoted by unity, and the velocity will then be inversely as the body or quantity of matter; hence we have $8 : 20 :: 100 : 250$; so that the velocity of the lesser body to produce the same effect as the greater must be 250 feet per second.

Example 3. Suppose one body to move 40 times faster than another, but the swifter body has been in motion only one minute, whereas the slower body has been in motion two hours; what is the ratio of the spaces described by the two bodies, and what is the space described by the slower body, supposing that described by the swifter to be 220 feet?

Here we have given the proportional velocities and the proportional times to find the proportional spaces; the solution of the question will therefore be found by the third general analogy, since that includes the terms of velocity, time, and space. The process indicated by the analogy is as follows, viz.: As the greater velocity multiplied by its time, is to the lesser velocity multiplied by its time, so is the space passed over by the swifter body, to the space passed over by the slower.

Here the velocities are as 40 to 1 and the times as 120 to 1, there being 120 minutes in two hours; the ratio of the spaces must therefore be as 40×1 to 1×120, or as 1 to 3; that is, the space passed over by the swifter motion is to that passed over by the slower as 1 to 3; but the space passed over by the swifter body in one minute is 220 feet, consequently the space passed over by the slower body in two hours is 660 feet.

Example 4. If one body moves with 5 times the velocity of another body, and by so doing passes over 10 miles for the other's one; what is the ratio of the times that the bodies have been in motion?

This question is also resolved by the third general analogy, where the time is proportional to the space divided by the velocity: thus we have $\frac{10}{5} : \frac{1}{1}$, or the times are as 2 to 1; that is, the swifter body has been in motion twice as long as the slower body. In this way may any other question respecting uniform motions be resolved, so that the reader will see how important it is to possess a knowledge of the principles contained in the above general propositions or analogies. We now proceed to the consideration of constant and uniform forces.

GENERAL LAWS OF CONSTANT FORCES.

The *quantity of motion*, or the *momentum* generated by a constant and uniform force acting for any time, is proportional to the force multiplied by the time. For let us conceive the time to be divided into a great number of indefinitely small elementary parts, then will the momentum generated in each part be the same, and consequently the whole momentum will be proportional to the whole time of acting, or to the sum of the indefinitely small elementary parts into which it is supposed to be divided. But the momentum for each small portion of time is proportional to the force that produces it; and consequently the whole momentum is proportional to the force and time of acting. Hence it follows conversely, that the quantity of motion or the momentum lost or destroyed in any time, is also proportional to the force and time of acting; this is evident, for whatever momentum or quantity of motion is generated by a given force in a given time, the same momentum or quantity of motion will be destroyed in the same time by an equal and opposite force. Consequently, when any constant and uniform force acts for a given time, the velocity generated or destroyed in that time is proportional to the force multiplied by the time and divided by the body or quantity of matter put in motion.

When bodies are urged by constant and uniform forces acting for given times, the spaces passed through during those times are proportional to the forces multiplied by the squares of the times and divided by the mass or quantity of matter; or the spaces are proportional to the squares of the times when the forces and bodies are given. But when the force and quantity of matter are given, the space is proportional to the time multiplied by the velocity, for the space actually passed through is equal to half the time of description multiplied by the velocity: consequently, the space that is actually described by a constant and uniform force in any given time is just half what would be described with the acquired velocity continued uniformly during that time. The space described in any given time by a constant and uniform force acting during that time is proportional to the square of the velocity. This is evident, for the velocity is proportional to the time; and we have shown that when the force and quantity of matter are constant, the space is proportional to the square of the time, and consequently proportional to the square of the velocity, for the velocity is proportional to the time.

From the principles here specified in reference to constant forces, combined with those in the foregoing class in regard to motion, we are enabled to deduce rules for resolving all questions relating to motions uniformly accelerated; but in order to render the references more distinct, we here collect the principles on which all the processes of computation depend; and it is only for the reader to select that which is appropriate to the solution of the question in hand. The general principles that involve the doctrine of uniform and constant forces are as follows.

1. The momentum or quantity of motion is proportional to the body or mass multiplied by the velocity.
2. The momentum or quantity of motion is proportional to the force multiplied by the time of acting.
3. The space described is proportional to the time multiplied by the velocity.
4. The velocity is proportional to the force multiplied by the time and divided by the body or mass.

These are the general analogies which exhibit the combinations of data sufficient to resolve all the ordinary questions, respecting accelerated motion. They do, however, in certain cases, require modifications to suit them for the purpose in hand: but as it is contrary to our plan to pursue the several steps of transposition, substitution, &c., we leave that to be performed by the operator; it is, however, presumed that the cases in which it will be necessary are very few. The following are the terms that enter the general analogies:—

1 The *body, mass,* or *quantity of matter,* moved.
2. The *motive force* or *agent* by which it is put in motion.
3. The *time* the motive force or agent continues to act.
4. The *velocity* generated during the time of action.

5. The *space* described by the body during the time the force acts.
6. The *momentum* or *quantity of motion* generated at the end of the time.

With these elements and the four analogies above specified can every particular respecting constant and uniform forces be ascertained.

LAWS OF FALLING BODIES.

Before we proceed to illustrate the application of the foregoing principles and analogies by the resolution of particular numerical examples, it becomes necessary to say a few words on the laws of gravity, or that force by which bodies descending in free space have a tendency to approach the earth in right lines directed to its centre. This force is general, and pervades all nature; it is also uniform, and constantly of the same intensity at all places near the earth's surface, or at equal distances from its central point: consequently, bodies descend towards the earth by a force that acts constantly and equally, and hence it follows that all the theorems and proportions that we have given above for constant or uniform forces are equally true with respect to the motions of bodies descending by the power of gravity, or the law of ACCELERATED MOTION IN FALLING BODIES. GALILEO was the first who directed the attention of philosophers to the existence of a gravitating power in bodies, but it was reserved for Sir ISAAC NEWTON to detect the laws of its operation and to demonstrate its universality. By the labours of Newton we are put in possession of the fact, that, by the force of gravity, all bodies, whether light or heavy, fall perpendicularly through equal spaces in equal times, supposing the motions to be made in vacuo. Thus, for instance, a piece of gold or a little gossamer will fall from the top to the bottom of an exhausted receiver in the very same space of time, and so will a piece of lead and a feather, the relative weights of bodies having no influence whatever in facilitating the descents in free space, the difference of motion that we observe to take place in bodies falling through the air being occasioned solely by the resistance which they meet with from that fluid in their descent. Such, then, is the nature of gravity; and it has been found by numerous very delicate and accurate experiments that the velocities acquired by bodies in descending freely by their own weight are directly proportional to the times of descent; that is, a body will acquire twice the velocity in falling two seconds that it will acquire in one second, and in three seconds the velocity will be triple what it is in the first. Another and a very important law of falling bodies discovered by experiment is, that the spaces described or fallen through in any time are directly proportional to the squares of the times of descent; but the velocities are as the times, consequently the spaces described are directly proportional to the squares of the velocities: it therefore follows that the weights, or gravities of bodies are proportional to the quantities of matter which they contain, and that the spaces, times, and velocities have to each other the relations that we have attributed to constant or uniform forces in the foregoing general theorems and analogies.

If a heavy body be thrown directly upwards, with the same velocity which it acquires in falling from a given height, it will lose all its motion in the same interval of time that it occupied in descending to acquire the velocity of projection, and it will ascend to precisely the same height from which it fell to acquire the said velocity. It will moreover describe equal spaces in equal times both in falling and rising, but in a reverse order; and it will have equal velocities at any particular point in the line of direction, whether the motion be upwards or downwards. This is obvious, for the same active force will generate or destroy the same quantity of motion in the same interval of time. In ascending above the surface of the earth the force of its attraction diminishes as the distance from the centre increases, and the law of diminution is inversely as the square of the distance from the central point, so that if a body were carried to a height equal to half the diameter of the earth above its surface, it will only be attracted with one fourth of the force with which it is attracted at the surface; thus bodies in ascending lose part of their weight. In like manner, the force of attraction in bodies situated within the earth or beneath its surface diminishes as the distance from the centre diminishes, so that the force of attraction or gravitation is directly proportional to the distance from the central point; hence it follows, that a body situated midway between the centre and surface, will gravitate with only half the force; it therefore appears that the force of attraction or gravitation is a maximum at the surface. It is also found by experiment that the force of attraction is slightly different at different parts of the earth's surface, being greatest at the poles and least at the equator: this arises from two causes, viz., from the spheroidal figure of the earth, and from the centrifugal force arising from its rotation on its axis: but in all places to which we have access, and for all practical purposes, the effects of these causes may be wholly overlooked, and the action of gravity may be considered uniform, and constantly the same, as we have already stated it to be at the opening of this discussion.

The force or intensity of gravity in the latitude of *London* is such, that a body descending freely by its own weight falls through a space of sixteen feet and one inch, or $16\frac{1}{12}$ feet in one second of time, and at the end of one second it has acquired a velocity which, if uniformly continued, would carry it through a space of thirty-two feet two inches, or $32\frac{1}{6}$ feet in the next second of time, and this velocity is conventionally assumed by mathematicians as the measure of the power of gravity, and, being constant, it becomes an element of calculation in all our inquiries relative to the motions and effects of constant or uniform forces.

Since the velocities are directly proportional to the times of falling from rest, and the spaces described as the squares of the times, or the squares of the velocities; then, as one second of time is to any number of seconds, so is the measure of the power of gravity to the velocity acquired. As the square of one second is to the square of the number of seconds, so is the space fallen in one second to the space described. And from these general analogies, combined with the standard experimental numbers, we deduce the following equations relative to the descents of gravity, and, since they are of very great use in mechanical calculations, we shall be somewhat particular in their discussion, the space described being always expressed in feet, and the time in seconds.

The space described by a falling body in any time is equal to the square of the time, multiplied by the descent in one second; or it is equal to the square of the velocity divided by twice the measure of the power of gravity, or one half the time multiplied by the velocity. From the first of these equations the space descended is determinable from the time; by the second it is found from the velocity; and by the third, it is assignable from the time and velocity conjointly. The second of these forms is one of very frequent occurrence, and to it we particularly direct the reader's attention, as it will be often employed in the course of the present work.

The velocity acquired by a falling body in any time is equal to the measure of the power of gravity, multiplied by the time, or it is equal to twice the space divided by the time, or the square root of twice the measure of the power of gravity multiplied by the space fallen in the given time

The time of descent in falling bodies is equal to the velocity acquired, divided by the measure of the power of gravity; or it is equal to twice the space divided by the velocity, or the square root of the whole space fallen, divided by the fall in one second. From these equations several others might be deduced relative to the space fallen in one second, but as they are less useful in calculations than those expressed above, we shall not trouble our readers with them.

Since the times of falling are directly proportional to the generated velocities, and the spaces described proportional to the squares of both the times and velocities, that is, proportional to the squares of either of them; it follows, that if the times of descent be represented by the series of consecutive numbers, 1″, 2″, 3″, 4″ &c., the corresponding velocities at the end of the times will be respectively represented by $32\frac{1}{6}$, $64\frac{1}{3}$, $96\frac{1}{2}$, $128\frac{2}{3}$ &c. feet per second, while the spaces described at the end of each second are expressed by the numbers $16\frac{1}{12}$, $48\frac{1}{4}$, $80\frac{5}{12}$ $112\frac{7}{12}$ &c. feet; and the spaces described in the whole times from the beginning of the descent are $16\frac{1}{12}$, $64\frac{1}{3}$, $144\frac{3}{4}$, $257\frac{1}{3}$ &c. feet respectively. The generation of these numbers is very easily understood; thus, in the first interval, or second of time, the force of gravity carries the body through a space of $16\frac{1}{12}$ feet, and in that time it generates a velocity such as, if uniformly continued, would describe twice the space, or $32\frac{1}{6}$ feet in the next second or interval, independently of the action of gravity; but the force of gravity still continuing to act with the same intensity as in the first interval, it will manifestly urge the body through an equal space, and this is in addition to that described by the uniform motion of $32\frac{1}{6}$ feet; so that the whole space generated in the second interval is $32\frac{1}{6}+16\frac{1}{12}=48\frac{1}{4}$; that is, $32\frac{1}{6}$ described uniformly, and $16\frac{1}{12}$ described by the force of gravity: consequently, the entire space described during the first and second intervals is equal to the sum of the spaces described in these intervals considered separately; that is, $16\frac{1}{12}+48\frac{1}{4}=64\frac{1}{3}$ feet. Again, at the end of the second interval, the body has acquired a velocity such as, being uniformly continued, would carry it through a space of $64\frac{1}{3}$ feet in the third interval or second of time, independently of the power of gravity: but since gravity still continues to exert itself with the same constant intensity, it will urge the body through a space of $16\frac{1}{12}$ feet in addition to that described by the constant velocity; and consequently the entire space described in the third interval by the force of gravity and the uniform velocity conjointly is $16\frac{1}{12}+64\frac{1}{3}=80\frac{5}{12}$ feet, and the total space described in the three intervals that have elapsed since the beginning of the motion must be equivalent to the sum of the spaces described in each of them separately; that is, $16\frac{1}{12}+48\frac{1}{4}+80\frac{5}{12}=144\frac{3}{4}$ feet. By pursuing a similar mode of reasoning for the successive intervals in the series the manner in which the velocity of a falling body is generated will be rendered intelligible, and the beautiful law of gravity, which exercises such an extensive influence in the material world, will be clearly comprehended. The following table exhibits the velocities acquired in each second, the spaces described in each second, and the total spaces described from the beginning of the motion to the end of each second.

		Space described. feet.	Total Space. feet.
Velocity acquired in the first interval	$32\frac{1}{6}$ feet.	$16\frac{1}{12}$	$16\frac{1}{12}$
second	$64\frac{1}{3}$	$48\frac{1}{4}$	$64\frac{1}{3}$
third	$96\frac{1}{2}$	$80\frac{5}{12}$	$144\frac{3}{4}$
fourth	$128\frac{2}{3}$	$112\frac{7}{12}$	$257\frac{1}{3}$
fifth	$160\frac{5}{6}$	$144\frac{3}{4}$	$402\frac{1}{12}$
sixth	193	$177\frac{1}{12}$	579
seventh	$225\frac{1}{6}$	$209\frac{1}{4}$	$788\frac{1}{12}$
eighth	$257\frac{1}{3}$	$241\frac{1}{12}$	$1029\frac{1}{3}$
ninth	$289\frac{1}{2}$	$273\frac{7}{12}$	$1302\frac{3}{4}$
&c.	&c.	&c.	&c.

This table might obviously be carried on to any extent; but what we have here set down will enable the attentive reader to trace every particular respecting the times, spaces, and velocities of bodies descending perpendicularly by the power of gravity. We shall therefore now proceed to illustrate the application of these principles and laws to practice, by resolving a few numerical examples.

Example 1. Suppose a leaden bullet which weighs 24 lbs. to be let fall from a height of 404 feet, which corresponds to the height of St. Paul's Cathedral; with what velocity will the ball strike the ground, and what will be the momentum or force of impact?

In this example we have given the space, the force, and the body or mass, and wish to find the velocity, and the momentum. Here it is manifest that the force implied in the question is the power of gravity, and the body or mass is the weight of the ball; but we have shown that the squares of the velocities are as the spaces fallen; it therefore follows, that,

$$16\tfrac{1}{12} : (32\tfrac{1}{6})^2 :: 404 : 25990\tfrac{2}{3},$$

and by extracting the square root, we get $\sqrt{25990\tfrac{2}{3}} = 161{\cdot}216$ feet per second, the velocity sought. But by the first of our general analogies for constant or uniform forces, the momentum is proportional to the mass multiplied by the velocity; consequently, we have $161{\cdot}216 \times 24 = 3869{\cdot}184$lbs., for the momentum or force of impact. It will readily be perceived that this case applies to the operation of the pile engine, for we have given the weight of the ram and the height of the fall to determine the vehemence of the stroke or the force of impact; and in applying the general analogies which we have given for constant or uniform forces to the determination of the velocity in this example, we have to consider the force and the mass or body, as constant or given quantities, as they are in reality; they may therefore be left out of the expression altogether, so that the space is simply proportional to the square of the velocity; but in falling bodies, the space descended in one second is $16\tfrac{1}{12}$ feet, and the velocity generated in that time is $32\tfrac{1}{6}$ feet; these quantities therefore become constants of comparison in all cases of a similar nature: hence the reason of the above process. But it may here be remarked, that precisely the same result would be obtained by adopting any other pair of corresponding numbers in the preceding table.

Example 2. Suppose a stone to be let fall from a height of 400 feet; in what time will it reach the ground, and what will be the momentum or force of impact, the weight of the stone being 336 lbs.?

Here we have given the weight of the body, and the space which it describes, to find the time of falling and the momentum acquired. In finding the time of descent, the weight of the body does not enter into the investigation; for, as we have already stated, all bodies, whether light or heavy, fall through equal spaces in equal times. Therefore, by seeking for the solution from our general analogies, we must consider the body and the force, which are constant, to be expunged from the expression, a condition that will lead us immediately to the principle of falling bodies, that the spaces are directly proportional to the squares of the times: now, the space fallen in one second of time is $16\tfrac{1}{12}$ feet; therefore we have,

$$16\tfrac{1}{12} : 1^2 :: 400 : 24{\cdot}87,$$

the square of the time of descending 400 feet, and the square root of this is $\sqrt{24{\cdot}87} = 4{\cdot}987.''$, the time required. Now, in order to find the momentum or force of impact, it is necessary to calculate either the force or velocity; but the velocity being the most easily determined after the manner of the first example, it will be preferable to employ it; we therefore get $\sqrt{64\tfrac{1}{3} \times 400} \times 336 = 53900$lbs. the momentum sought.

Example 3. Suppose a stone to be dropped from the top of a tower and left to descend freely by means of its own gravity; what is the height of the tower, if the stone strike the ground at the end of the fourth second?

In this example we have given the time and the force to find the space; in order, therefore, to resolve the question by our general analogies, we must consider both the force and the mass to be constant, and, by expunging them from the expression, we arrive at that case of falling bodies in which the space is directly proportional to the square of the time. Now, the space fallen in one second is $16\tfrac{1}{12}$ feet; hence we have $1^2 : 16\tfrac{1}{12} :: 4^2 : 257\tfrac{1}{3}$ feet, which is the space described by gravity in four seconds, according to the foregoing table of times, spaces, and velocities.

Example 4. Let every thing remain as in the foregoing question, with what velocity does the stone impinge upon the ground, and what is the momentum or force of impact, supposing the stone to weigh 112 lbs.?

Here we have given the time, body, and force, to determine the velocity and momentum. Therefore, in seeking the solution by the general analogies we must suppose the body and force to be constant, and by expunging them from the expression in which they are found in combination with the time, we obtain the very simple case of falling bodies, that the velocity is directly proportional to the time of descent. Now the velocity acquired by gravity in one second is $32\tfrac{1}{6}$ feet; hence we have $1'' : 32\tfrac{1}{6} :: 4'' : 128\tfrac{2}{3}$ feet, the velocity sought, as is manifest also from the foregoing table. But the momentum is equal to the mass drawn into the velocity; hence it is $128\tfrac{2}{3} \times 112 = 14421\tfrac{1}{3}$ lbs., the momentum required.

Example 5. If a stone dropped from the summit of a tower be observed to strike the ground with a velocity of 120 feet per second; it is required to determine the height of the tower, the time of descent, and the momentum or force of impact?

Here we have given the motive or moving force, which is gravity, the body or mass, and the velocity, to find the space described, the time of descent, and the momentum. Supposing the mass and the motive force to be constant, they are expunged from the expression, and we are led to the fact that the spaces described are directly proportional to the squares of the velocities; and as the velocity acquired by gravity in one second is $32\tfrac{1}{6}$ feet, and the space fallen is $16\tfrac{1}{12}$ feet, while the given velocity is 120 feet: we have $32\tfrac{1}{6}^2 : 16\tfrac{1}{12} :: 120^2 : 223.834$ feet, the height required. In like manner, by seeking the time from the general analogies, we have only to expunge the motive force and the body considered as constant, and we are led to the case in which the velocities are simply proportional to the times in which they are generated; hence we have $32\tfrac{1}{6} : 1'' :: 120 : 3\tfrac{141}{193}''$, the time of descent sought. But the terminal velocity is given by the question; hence the momentum or quantity of motion is $120 \times 56 = 6720$ lbs.

It would occupy too much space to illustrate every combination of data comprehended in the theory here set forth; those cases which we have exemplified are the most important in practice, and the method we have shown of applying them will, if properly attended to, guide the reader to the reduction of any other case that is likely to occur in inquiries connected with the steam engine. We have not, however, in any of the examples, exhibited the actual reduction of the analogy, by which the answer is determined; but since the finding of the space descended involves a somewhat more complex operation, we shall here show the method of performing it:—

Velocity acquired by gravity in one second, $32\tfrac{1}{6}$ ar. co. log.*	- -	8·492594
		2
		6·985188
Space descended in one second by gravity, $16\tfrac{1}{12}$	- - -	log. 1·206376
Velocity with which the stone strikes the ground, 120	-	2 x log. 4·158362
Nat. num. or height fallen through 223·834 feet	-	sum of the logs. 2·349926

From the examples here selected and resolved, the reader will perceive the very great importance of a familiar acquaintance with the doctrine of impulsive and constant or uniform forces, which, together with the laws of gravity just discussed, enter more or less into all mechanical inquiries.

COMPOSITION AND RESOLUTION OF MOTION AND FORCES.

A body will describe the diagonal of a parallelogram by the action of two several forces combined, in the same time that it would describe one or other of the sides, by one or other of the forces separately considered.

Let A B C D, *fig.* 26, be a parallelogram, of which the diagonal is A D; then if a body at A be acted on separately by two forces in the directions A B and A C, which would cause the body to be carried through the spaces A B and A C in the same time, then both forces acting at once will cause the body to be carried through the diagonal A D of the parallelogram. For, let the straight line A C be supposed to move from the position A C, in a direction always parallel to itself; whilst the body at A moves along the line A C in such a manner as to arrive at the point *b*, when A C coincides with *a c*. Then since the lines A B and A C are described in the same time, and A *a* and A *b* are also described in the same time; and since the motions are uniform, A *a* : *a b* :: A B : B D, and therefore A *b* D is a straight line coinciding with A D the diagonal of the parallelogram. The magnitude of the three forces acting in the directions A B, A C and A D; that is the magnitude of the forces acting in the directions of the sides and the diagonal of a parallelogram, are respectively proportional to those sides and diagonal, or proportional to the lines A B, A C and A D. Any single force A D, denoted by the diagonal of a parallelogram, is equivalent in magnitude to two forces denoted by the side A B and A C; that is, a single force acting in the direction of the diagonal A D, and having its magnitude proportional thereto, produces the same effect as two forces acting in the directions of the sides A B and A C, and having their magnitudes proportional thereto. Consequently, any single force A D may be resolved into two forces an infinite number of ways by drawing any two lines A B and A C to represent their magnitudes and the directions in which they act. The operation of finding a single force that shall produce the same effect as two or more forces, whose magnitudes and directions are given, is called the *Composition of Forces.*

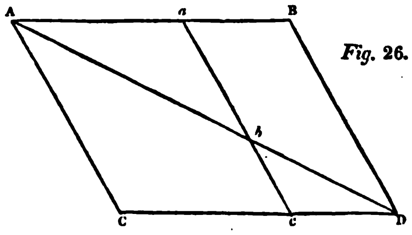


Fig. 26.

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* The contracted words, "ar. co. log.," mean simply the arithmetical complement of the logarithm, or the logarithm of the given number subtracted from 10. The use of it avoids the trouble of subtracting the first logarithm from the sum of the other two, as it is necessary to do in working out the proportion.

The converse of this, or the operation of finding two or more forces whose effects shall be equivalent to a single given force, is called the *Resolution of Forces;* the single force being called the *Resultant*, and the other forces to which the Resultant is equivalent, are called the *Composants.* The figure A B D C by which the composants and resultant are expounded is called the *Parallelogram of Forces.*

If three forces acting at a material point in a body keep each other in equilibrio, they will have to each other the proportions of the three sides of a triangle drawn parallel to the lines of their directions. And if three forces acting against each other maintain an equilibrium, these forces will be respectively proportional to the three sides of a triangle drawn perpendicular to the lines of their directions, or making any given angle with them on the same side. If three forces acting at a material point of a body keep one another in equilibrio, they will be respectively proportional to the sines of the angles made by the mutual concourse of the lines of their directions. If any number of forces acting against one another are kept in equilibrio by their mutual actions, they may all be reduced to two equal and opposite ones. For by composition any two of the forces may be reduced to a single one acting in the same plane; and this last force may be compounded with any of the remaining forces, so that their resultant may also act in the same plane with them, and this again may be compounded with another, and so on, until the whole system is at last reduced to the action of two equal and opposite forces.

If three forces sustain one another in equilibrio by their mutual actions, the line of direction of each force will pass through the point of concourse of the directions of the other two. And if two forces to be compounded act in the same line, either both the same way or the one directly opposite the other, then their resultant will act in the same line also, and it will be equal to the sum or the difference of the composants, according as they act in the same or opposite directions. The above properties hold true of all similar forces, whether they be instantaneous or continual, or whether they act by impulse or percussion, by pressing, weighing or pushing; and we must commend the subject to the attention of our readers as one of much importance in all mechanical inquiries.

COLLISION OF BODIES.

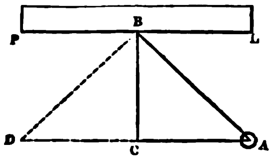


Fig. 27.

If a body impinge or act against a plane surface, it exerts its force in a direction perpendicular to the surface on which it acts. Let the body at A *fig.* 27.), moving in the direction AB with a given velocity, impinge upon a hard and solid body at B; it is proposed to show that the body at A acts on the plane PL in a direction at right angles to its surface. Let the straight line AB represent the magnitude and direction of the force with which the body strikes the plane, and AB be resolved into the two forces AC and BC, the one of them in a direction parallel to the plane, and the other perpendicular to it; then it is evident that the force AC, which is parallel to the plane, can have no effect upon it; and, consequently, the body or plane PL is only acted on by the force in the direction CD, which is perpendicular to its surface. Hence, if one body impinges on another body with a given velocity, the magnitude or intensity of the stroke or force of impact is directly proportional to the sine of the angle of incidence, or the angle in which the direction of the body meets the plane. This is evident, for the actual force is represented in magnitude and direction by AB, and the force acting on the surface is CB; but CB is the sine of the angle BAC to the radius AB, and BAC is equal to ABL, the angle in which the line of direction meets the plane.

If an elastic body A impinge on a hard and elastic plane PL, the angles of incidence and reflection are equal to one another. For if AD be parallel to PL, the motion of A, parallel to the plane, is not at all affected by the stroke; and in consequence of the elasticity of one or both bodies, the body A is reflected back to D in the same time that it moved from A to B. AC is equal to CD, being described in equal times; consequently the angle ABC is equal to the angle DBC, and the angle ABL is equal to the angle DBP.

If a non-elastic body impinge on another non-elastic body, it loses only half the motion that would be lost if the bodies were elastic. This is clear, for non-elastic bodies only stop without rebounding or receding from one another, but elastic bodies recede with the same velocity.

The sum of the motions of two or more bodies in any direction towards the same parts cannot be influenced or changed by the action of the bodies on each other. If any two bodies move the same way, since action and reaction are equal and contrary, what the one loses the other gains, and consequently the sum of the motions remains the same as before, and the same thing holds true if there were more than two bodies. When bodies strike each other obliquely, they act on each other in a direction perpendicular to the surface acted on; and consequently, by the law of action and re-action, there is no change produced of that direction. But in a direction parallel to the surface struck, the bodies have no effect on each other, therefore the motion is not altered in that direction, and consequently the motions remain the same in any one line of direction.

Motion considered in one direction can neither be increased nor decreased, but must constantly remain the same under all circumstances. This follows immediately from what has just been stated, for whatever motion is gained by one body by addition is lost to the other body by subtraction, and consequently the sum total of the two motions remains the same as before. The principle here enunciated, however, does not hold with regard to motions in all directions, for in this case motions may be increased and decreased an indefinite number of ways; thus, if two equal non-elastic bodies meet each other, both their motions are destroyed by the stroke: here, at the beginning of the movement, they had both of them a certain quantity of motion estimated in contrary directions, but on meeting each other both their motions are destroyed.

The motions of bodies included in a given space are the same with respect to each other, whether that space stands still or moves uniformly in a right line. For if any body be moving in a right line, and if any force be equally impressed upon both the body and the line in which it moves, this will produce no change in the motion of the body along the straight line, and for the same reason the motions of all the other bodies in their respective directions will also remain the same; consequently, the motions of the bodies amongst themselves will still be the same, whether the space by which they are included be at rest or moving uniformly in a straight line, their mutual actions on one another remaining the same in both cases.

CENTRE OF GRAVITY.

The centre of gravity of a body is that point within it which continually endeavours to gain the lowest possible situation; or it is that point on which the body, being freely suspended, will remain at rest in all positions. The centre of gravity of a body does not always exist within the matter of which the body is composed, there being bodies of such forms as to preclude the possibility of this being the case, but it must either be surrounded by the constituent matter, or so placed that the particles shall be symmetrically situated, with respect to a vertical line in which the position of the centre occurs. Thus, the centre of gravity of a ring is not in the substance of the ring itself, but if the ring be uniform it will be in the axis of its circumscribing cylinder; and if the ring varies in form or density, it will be situated nearest to those parts where the weight or density is greatest. Varying the position of a body will not cause any change in the situation of the centre of gravity; for any change of position the body undergoes will only have the effect of altering the directions of the sustaining forces, which will still preserve their parallelism. When a body is suspended by any other point than its centre of gravity, it will not rest unless that centre be in the same vertical line with the point of suspension; for in every other position the force which is intended to ensure the equilibrium will not directly oppose the resultant of gravity upon the particles of the body, and of course the equilibrium will not obtain; the directions of the forces of gravity upon the constituent particles are all parallel to one another and perpendicular to the horizon. If a heavy body be sustained by two or more forces, their lines of direction must meet either at the centre of gravity, or in the vertical line in which it occurs.

A body cannot descend or fall downwards, unless it be in such a position that by its motion the centre of gravity descends. If a body stands on a plane, and a line be drawn perpendicular to the horizon, and if this perpendicular line fall within the base of the body, it will be supported without falling; but if the perpendicular falls without the base of the body it will overset. For when the perpendicular falls within the base the body cannot be moved at all without raising the centre of gravity; but when the perpendicular falls without the base towards any side, if the body be moved towards that side, the centre of gravity will descend, and consequently the body will overset in that direction. If a perpendicular to the horizon from the centre of gravity fall upon the extremity of the base, the body may continue to stand, but the least force that can be applied will cause it to overset in that direction; and the nearer the perpendicular is to any side the easier the body will be made to fall on that side, but the nearer the perpendicular is to the middle of the base the firmer the body will stand. If the centre of gravity of a body be supported, the whole body is supported, and the place of the centre of gravity must be considered as the place of the body, and it is always in a line which is perpendicular to the horizon.

In any two bodies, the common centre of gravity divides the line that joins their individual centres into two parts that are to one another reciprocally as the magnitudes of the bodies. The products of the bodies multiplied by their respective distances from the common centre of gravity are equal. If a weight be laid upon any point of an inflexible lever which is supported at the ends, the pressure on each point of the support will be inversely as the respective distances from the point where the weight is applied. In a system of three bodies, if a line be drawn from the centre of gravity of any one of them to the common centre of the other two, then the common centre of all the three bodies divides the line into two parts that are to each other reciprocally as the magnitude of the body from which the line is drawn to the sum of the magnitudes of the other two; and, consequently, the single body multiplied by its distance from the common centre of gravity is equal to the sum of the other bodies multiplied by the distance of their common centre from the common centre of the system.

If there be taken any point in the straight line or lever joining the centres of gravity of two bodies, the sum of the two products of each body multiplied by its distance from that point is equal to the product of the sum of the bodies multiplied by the distance of their common centre of gravity from the same point. The two bodies have, therefore, the same tendency to turn the lever about the assumed point, as if they were both placed in their common centre of gravity. Or, if the line with the bodies moves about the assumed point, the sum of the momenta is equal to the momentum of the sum of the bodies placed at their common centre of gravity. The same property holds with respect to any number of bodies whatever, and also when the bodies are not placed in the line, but in perpendiculars to it passing through the bodies. If any plane pass through the assumed point, perpendicular to the line in which it subsists, then the distance of the common centre of gravity of all the bodies from that plain is equal to the sum of all the momenta divided by the sum of all the bodies. We may here specify the positions of the centre of gravity in several figures of very frequent occurrence.

In a straight line, or in a straight bar or rod of uniform figure and density, the position of the centre of gravity is at the middle of its length. In the plane of a triangle the centre of gravity is situated in the straight line drawn from any one of the angles to the middle of the opposite side, and at two thirds of this line distant from the angle where it originates, or one third distant from the base. In the surface of a trapezium the centre of gravity is in the intersections of the straight lines that join the centres of the opposite triangles made by the two diagonals. The centre of gravity of the surface of a parallelogram is at the intersection of the diagonals, or at the intersection of the two lines which bisect the figure from its opposite sides. In any regular polygon the centre of gravity is at the same point as the centre of magnitude. In a circular arc the position of the centre of gravity is distant from the centre of the circle by the measure of a fourth proportional to the arc, radius, and chord. In a semicular arc the position of the centre of gravity is distant from the centre by the measure of a third proportional to the arc of the quadrant and the radius. In the sector of a circle the position of the centre of gravity is distant from the centre of the circle by a fourth proportional to three times the arc of the sector, the chord of the arc, and the diameter of the circle. In a circular segment the position of the centre of gravity is distant from the centre of the circle by a space which is equal to the cube or third power of the chord divided by twelve times the area of the segment. In a semicircle the position of the centre of gravity is distant from the centre of the circle by a space which is equal to four times the radius divided by the constant number $3{\cdot}1416 \times 3 = 9{\cdot}4248$. In a parabola the position of the centre of gravity is distant from the vertex by three-fifths of the axis. In a semi-parabola the position of the centre of gravity is at the intersection of the co-ordinates, one of which is parallel to the base, and distant from it by two-fifths of the axis, and the other parallel to the axis, but distant from it by three-eighths of the semi-base.

The centres of gravity of the surface of a cylinder, a cone, and conic frustum, are respectively at the same distances from the origin as are the centres of gravity of the parallelogram, the triangle, and trapezoid, which are sections passing along the axes of the respective solids. The centre of gravity of the surface of a spheric segment is at the middle of the versed sine or height. The centre of gravity of the convex surface of a spherical zone is at the middle of that portion of the axis of the sphere intercepted by its two bases. In prisms and cylinders the position of the centre of gravity is at the middle of the straight line that joins the centres of gravity of their opposite ends. In pyramids and cones the centre of gravity is in the straight line that joins the vertex with the centre of gravity of the base, and at three-fourths of its length from the vertex, and one-fourth from the base. In a semisphere, or semispheroid, the position of the centre of gravity is distant from the centre by three-eighths of the radius. In a parabolic conoid the position of the centre of gravity is distant from the base by one-third of the axis, or two-thirds of the axis distant from the vertex. There are several other bodies and figures of which the position of the centre of gravity is known; but as the position in those cases cannot be defined without algebra, we omit them.

CENTRIPETAL AND CENTRIFUGAL FORCES.

Central forces are of two kinds, *centripetal* and *centrifugal*. *Centripetal force* is that force by which a body is attracted or impelled towards a certain fixed point as a centre, and that point towards which the body is urged is called the *centre of attraction* or the *centre of force*. *Centrifugal force* is that force by which a body endeavours to recede from the centre of attraction, and from which it would actually fly off in the direction of a tangent if it were not prevented by the action of the centripetal force. These two forces are therefore antagonistic; the action of the one being directly opposed to that of the other. It is on the joint action of these two forces that all curvilinear motion depends. Circular motion is that affection of curvilinear motion where the body is constrained to move in the circumference of a circle: if it continues to move so as to describe the entire circle, it is denominated *rotatory motion*, and the body is said to revolve in a circular orbit, the centre of which is called the centre of motion. In all circular motions the deflection or deviation from the rectilinear course is constantly the same at every point of the orbit, in which case the centripetal and centrifugal forces are equal to one another. In circular orbits the centripetal forces, by which equal bodies placed at equal distances from the centres of force are attracted or drawn towards those centres, are proportional to the quantities of matter in the central bodies. This is manifest, for since all attraction takes place towards some particular body, every particle in the attracting body must produce its individual effect; consequently, a body containing twice the quantity of matter will exert twice the attractive energy, and a body containing thrice the quantity of matter will operate with thrice the attractive force, and so on according to the quantity of matter in the attracting body.

Any body, whether large or small, when placed at the same distance from the centre of force, is attracted or drawn through equal spaces in the same time by the action of the central body. This is obvious from the consideration that although a body two or three times greater is urged with two or three times greater an attractive force, yet there is two or three times the quantity of matter to be moved; and, as we have shown elsewhere, the velocity generated in a given time is directly proportional to the force by which it is generated, and inversely as the quantity of matter in the moving or attracted body. But the force which in the present instance is the weight of the body is proportional to the quantity of matter which it contains; consequently, the velocity generated is directly and inversely proportional to the quantity of matter in the attracted body, and is, therefore, a given or a constant quantity. Hence the centripetal force, or force towards the centre of the circular orbit, is not measured by the magnitude of the revolving body, but only by the space which it describes or passes over in a given time. When a body revolves in a circular orbit, and is retained in it by means of a centripetal force directed to the centre, the actual velocity of the revolving body at every point of its revolution is equal to that which it would acquire by falling perpendicularly with the same uniform force through one-fourth of the diameter, or one half the radius of its orbit; and this velocity is the same as would be acquired by a second body in falling through half the radius, whilst the first body, in revolving in its orbit, describes a portion of the circumference which is equal in length to half the diameter of the circle. Consequently, if a body revolves uniformly in the circumference of a circle by means of a given centripetal force, the portion of the circumference which it describes in any time is a mean proportional between the diameter of the circle and the space which the body would descend perpendicularly in the same time, and with the same given force continued uniformly.

The *periodic time*, in the doctrine of central forces, is the time occupied by a body in performing a complete revolution round the centre, when that body is constrained to move in the circumference by means of a centripetal force directed to that point; and when the body revolves in a circular orbit, the periodic time, or the time of performing a complete revolution, is expressed by the term $\pi t \sqrt{\frac{d}{s}}$, and the velocity or space passed over in the time t will be $\sqrt{ds}$; in which expressions d denotes the diameter of the circular orbit described by the revolving body, s the space descended in any time by a body falling perpendicularly downwards with the same uniform force, t the time of descending through the space s and π the circumference of a circle whose diameter is unity. If several bodies revolving in circles round the same or different centres be retained in their orbits by the action of centripetal forces directed to those points, the periodic times will be directly as the square roots of the radii or distances of the revolving bodies, and inversely as the square roots of the centripetal forces, or, what is the same thing, the squares of the periodic times are directly as the radii, and inversely as the centripetal forces.

CENTRE OF GYRATION.

The *centre of gyration* is that point in which, if all the constituent particles, or all the matter contained in a revolving body, or system of bodies, were concentrated, the same angular velocity would be generated in the same time by a given force acting at any place as would be generated by the same force acting similarly on the body or system itself according to its formation.

The *angular motion* of a body, or system of bodies, is the motion of a line connecting any point with the centre or axis of motion, and is the same in all parts of the same revolving system.

In different unconnected bodies, each revolving about a centre, the angular velocity is directly proportional to the absolute velocity, and inversely as the distance from the centre of motion; so that, if the absolute velocities of the revolving bodies be proportional to their radii or distances, the angular velocities will be equal. If the axis of motion passes through the centre of gravity, then is this centre called the principal centre of gyration.

The distance of the centre of gyration from the point of suspension, or the axis of motion in any body or system of bodies, is a geometrical mean between the centres of gravity and oscillation from the same point or axis; consequently, having found the distances of these centres in any proposed case, the square root of their product will give the distance of the centre of gyration. If any part of a system be conceived to be collected in the centre of gyration of that particular part, the centre of gyration of the whole system will continue the same as before; for the same force that moved this part of the system before along with the rest will move it now without any change; and consequently, if each part of the system be collected into its own particular centre, the common centre of the whole system will continue the same. If a circle be described about the centre of gravity o any system, and the axis of rotation be made to pass through any point o the circumference, the distance of the centre of gyration from that poi will always be the same.

If the periphery of a circle revolve about an axis passing through the centre, and at right angles to its plane, it is the same thing as if all the matter were collected into any one point in the periphery. And moreover, the plane of a circle or a disk containing twice the quantity of matter as the said periphery, and having the same diameter, will in an equal time acquire the same angular velocity. If the matter of a revolving body were actually to be placed in the centre of gyration, it ought either to be arranged in the circumference, or in two points of the circumference diametrically opposite to each other, and equally distant from the centre of motion, for by this means the centre of motion will coincide with the centre of gravity, and the body will revolve without any lateral force on any side. These are the chief properties connected with the centre of gyration, and the following are a few of the cases in which its position has been ascertained.

In a right line, or a cylinder of very small diameter revolving about one of its extremities, the distance of the centre of gyration from the centre of motion is equal to the length of the revolving line or cylinder multiplied by the square root of $\frac{1}{3}$. In the plane of a circle, or a cylinder revolving about the axis, it is equal to the radius multiplied by the square root of $\frac{1}{2}$. In the circumference of a circle revolving about the diameter it is equal to the radius multiplied by the square root of $\frac{1}{2}$. In the plane of a circle revolving about the diameter it is equal to one half the radius. In a thin circular ring revolving about one of its diameters as an axis it is equal to the radius multiplied by the square root of $\frac{1}{2}$. In a solid globe revolving about the diameter it is equal to the radius multiplied by the square root of $\frac{2}{5}$. In the surface of a sphere revolving about the diameter it is equal to the radius multiplied by the square root of $\frac{2}{3}$. In a right cone revolving about the axis it is equal to the radius of the base multiplied by the square root of $\frac{3}{10}$. In all these cases the distance is estimated from the centre of the axis of motion. We shall have occasion to illustrate these principles when we come to treat of fly-wheels in the construction of the different parts of steam engines.

When bodies revolving in the circumferences of different circles are retained in their orbits by centripetal forces directed to the centres, the periodic times of revolution are directly proportional to the distances or radii of the circles, and inversely as the velocities of motion; and the periodic times, under like circumstances, are directly as the velocities of motion, and inversely as the centripetal forces. If the times of revolution are equal, the velocities and centripetal forces are directly as the distances or radii of the circles. If the centripetal forces are equal, the squares of the times of revolution and the squares of the velocities are as the distances or radii of the circles. If the times of revolution are as the radii of the circles, the velocities will be equal, and the centripetal forces reciprocally as the radii.

If several bodies revolve in circular orbits round the same or different centres, the velocities are directly as the distances or radii, and inversely as the times of revolution. The velocities are directly as the centripetal forces and the times of revolution. The squares of the velocities are proportional to the centripetal forces, and the distances or radii of the circles. When the velocities are equal, the times of revolution are proportional to the radii of the circles in which the bodies revolve, and the radii of the circles are inversely as the centripetal forces. If the velocities be proportional to the distances or radii of the circles, the centripetal forces will be in the same ratio, and the times of revolution will be equal.

If several bodies revolve in circular orbits about the same or different centres, the centripetal forces are proportional to the distances or radii of the circles directly, and inversely as the squares of the times of revolution. The centripetal forces are directly proportional to the velocities, and inversely as the times of revolution. The centripetal forces are directly as the squares of the velocities, and inversely as the distances or radii of the circles. When the centripetal forces are equal, the velocities are proportional to the times of revolution, and the distances as the squares of the times or as the squares of the velocities. When the central forces are proportional to the distances or radii of the circles, the times of revolution are equal. If several bodies revolve in circular orbits about the same or different centres, the radii of the circles are directly proportional to the centripetal forces, and the squares of the periodic times. The distances or radii of the circles are directly as the velocities and periodic times. The distances or radii of the circles are directly as the squares of the velocities, and reciprocally as the centripetal forces. If the distances are equal, the centripetal forces are directly as the squares of the velocities, and reciprocally as the squares of the times of revolution; the velocities also are reciprocally as the times of revolution. The converse of these principles and properties are equally true; and all that has been here stated in regard to centripetal forces is similarly true of centrifugal forces, they being equal and contrary to each other.

The quantities of matter in all attracting bodies, having other bodies revolving about them in circular orbits, are proportional to the cubes of the distances directly, and to the squares of the times of revolution reciprocally. The attractive force of a body is directly proportional to the quantity of matter, and inversely as the square of the distance. If the centripetal force of a body revolving in a circular orbit be proportional to the distance from the centre, a body let fall from the upper extremity of the vertical diameter will reach the centre in the same time that the revolving body describes one fourth part of the orbit. The velocity of the descending body at any point of the diameter is proportional to the ordinate of the circle at that point; and the time of falling through any portion of the diameter is proportional to the arc of the circumference whose versed sine is the space fallen through. All the times of falling from any altitudes whatever to the centre of the orbit will be equal; for these times are equal to one fourth of the periodic times, and these times, under the specified conditions, are equal. The velocity of the descending body at the centre of the circular orbit is equal to the velocity of the revolving body.

These are the chief principles that we need consider regarding the motion of bodies in circular orbits; and from them we are led to the consideration of bodies suspended on a centre, and made to revolve in a circle beneath the suspending point, so that when the body describes the circumference of a circle, the string or wire by which it is suspended describes the surface of a cone. A body thus revolving is called a *conical pendulum*, and this species of pendulum, or, as it is usually termed, the *governor*, is of great importance in mechanical arrangements, being employed to regulate the movements of steam engines, water-wheels, and other mechanism. As we shall have occasion to show the construction and use of this instrument when treating of the parts and proportions of engines, we need not do more at present than state the principles on which its action depends. We must, however, previously say a few words on the properties of the simple pendulum, or that which, being suspended from a centre, is made to vibrate from side to side in the same vertical plane.

PENDULUMS.

If a pendulum vibrates in a small circular arc, the time of performing one vibration is to the time occupied by a heavy body in falling perpendicularly through half the length of the pendulum as the circumference of a circle is to its diameter. All vibrations of the same pendulum made in very small circular arcs are made in very nearly the same time. The space described by a falling body in the time of one vibration is to half the length of the pendulum as the square of the circumference of a circle is to the square of the diameter. The lengths of two pendulums which by vibrating describe similar circular arcs are to each other as the squares of the times of vibration. The times of pendulums vibrating in small circular arcs are as the square roots of the lengths of the pendulums. The velocity of a pendulum at the lowest point of its path is proportional to the chord of the arc through which it descends to acquire that velocity. Pendulums of the same length vibrate in the same time whatever the weights may be. From which we infer, that all bodies near the earth's surface, whether they be heavy or light, will fall through equal spaces in equal times, the resistance of the air not being considered.

The lengths of pendulums vibrating in the same time in different positions of the earth's surface are as the forces of gravity in those positions. The times wherein pendulums of the same length will vibrate by different forces of gravity are inversely as the square roots of the forces. The lengths of pendulums vibrating in different places are as the forces of gravity at those places and the squares of the times of vibration. The times in which pendulums of any length perform their vibrations are directly as the square roots of their lengths, and inversely as the square roots of the gravitating forces. The forces of gravity at different places on the earth's surface are directly as the lengths of the pendulums, and inversely as the squares of the times of vibration. These are the chief properties of a simple pendulum vibrating in a vertical plane, and the principal problems that arise in connection with it are the following, viz:

To find the length of a pendulum that shall make any number of vibrations in a given time; and secondly, having given the length of a pendulum, to find the number of vibrations it will make in any time given. These are problems of very easy solution, and the rules for resolving them are simply as follow:—For the first, the rule is, *multiply the square of the number of seconds in the given time by the constant number* 39·1393, *and divide the product by the square of the number of vibrations, for the length of the pendulum in inches.* For the second, it is, *multiply the square of the number of seconds in the given time by the constant number* 39·1393, *divide the product by the given length of the pendulum in inches, and extract the square root of the quotient for the number of vibrations sought.* The number 39·1393 is the length of a pendulum in inches, that vibrates seconds, or sixty times in a minute, in the latitude of London.

Example 1. Suppose a pendulum is found to make 35 vibrations in a minute; what is the distance from the centre of suspension to the centre of oscillation?

Here, by the rule, the number of seconds in the given time is 60; hence we get $60 \times 60 \times 39·1393 = 140901·48$, which, being divided by $35 \times 35 = 1225$, gives $140901·48 \div 1225 = 115·021$ inches for the length required.

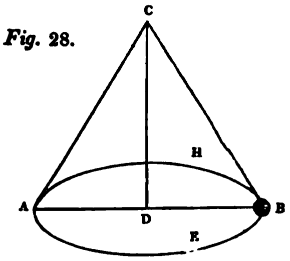
Example 2. The length of a pendulum between the centre of suspension and the centre of oscillation is 64 inches; what number of vibrations will it make in 60 seconds?

By the rule we have $60 \times 60 \times 39·1393 = 140901·48$, which, being divided by 64, gives $140901·48 \div 64 = 2264·0856$, and the square root of this is $\sqrt{2264·0856} = 47·58$, number of vibrations sought. When the given time is a minute or 60 seconds, as in the two examples proposed above, the product of the constant number 39·1393 by the square of the time, or 140901·48, is itself a constant quantity, which, being kept in mind, will in some measure facilitate the process of calculation in all similar cases. We now return to the consideration of the conical pendulum, or that in which the ball revolves about a vertical axis in the circumference of a circular plane which is parallel to the horizon.

CONICAL PENDULUM.

If a pendulum be suspended from the upper extremity of a vertical axis, and be made to revolve about that axis by a conical motion, which constrains the revolving body to move in the circumference of a circle whose plane is parallel to the horizon, then the time in which the pendulum performs a revolution about the axis can easily be found.

Fig. 28.



Let C D, *fig.* 28., be the pendulum in question, suspended from C, the upper extremity of the vertical axis C D, and let the ball or body B, by revolving about the said axis, describe the circle B E A H, the plane of which is parallel to the horizon; it is proposed to assign the time of description, or the time in which the body B performs a revolution about the axis C D, at the distance B D.

Conceive the axis C D to denote the weight of the revolving body, or its force in the direction of gravity; then, by the Composition and Resolution of Forces, already treated of, C B will denote the force or tension of the string or wire that retains the revolving body in the direction C B, and B D the force tending to the centre of the plane of revolution at D. But, by the general laws of motion and forces previously laid down, if the time be given, the space described will be directly proportional to the force; but, by the laws of gravity, the space fallen perpendicularly from rest, in one second of time, is $g = 16\frac{1}{12}$ feet; consequently we have $CD : BD :: 16\frac{1}{12} : \frac{16\frac{1}{12}.BD}{CD}$, the space described towards D by the force in B D in one second. Consequently, by the laws of centripetal forces, the periodic time, or the time of the body revolving in the circle B E A H, is expressed by the term $\pi\sqrt{\frac{2 \cdot CD}{16\frac{1}{12}}}$, where $\pi =$ 3·1416, the circumference of a circle whose diameter is unity; or putting t to denote the time, and expressing the height C D in feet, we get $t = 6{\cdot}2832 \sqrt{\frac{CD}{12 \times 32\frac{1}{6}}}$, or, by reducing the expression to its simplest form, it becomes $t = 0{\cdot}31986\sqrt{CD}$, where C D must be estimated in inches, and t in seconds. Here we have obtained an expression of great simplicity, and the practical rule for reducing it may be expressed in words, as follows:—

Rule. *Multiply the square root of the height, or the distance between the point of suspension and the centre of the plane of revolution, in inches, by the constant fraction* 0·31986, *and the product will be the time of revolution in seconds.*

Example. In what time will a conical pendulum revolve about its vertical axis, supposing the distance between the point of suspension and the centre of the plane of revolution to be 39·1393 inches, which is the length of a simple pendulum that vibrates seconds in the latitude of London?

The square root of 39·1393 is 6·2561; consequently, by the rule, we have, $6{\cdot}2561 \times 0{\cdot}31986 = 2{\cdot}0011$ seconds for the time of revolution sought. It consequently revolves 30 times in a minute, as it ought to do by the theory of the simple pendulum.

By reversing the process, the height of the cone, or the distance between the point of suspension and the centre of the plane of revolution, corresponding to any given time, can easily be ascertained; for we have only to divide the number of seconds in the given time by the constant decimal 0·31986, and the square of the quotient will be the required height in inches. Thus, suppose it were required to find the height of a conical pendulum that would revolve 30 times in a minute. Here the time of revolution is 2 seconds for $60 \div 30 = 2$; therefore, by division, it is $2 \div 0{\cdot}31986 = 6{\cdot}2527$, which, being squared, gives $6{\cdot}2527^2 = 39{\cdot}0961$ inches, or the length of a simple pendulum that vibrates seconds very nearly. In all conical pendulums the times of revolution, or the periodic times, are proportional to the square roots of the heights of the cones. This is manifest, for in the foregoing equation of the periodic time the numbers 6·2832 and 386, or $12 \times 32\frac{1}{6}$, are constant quantities, consequently t varies as $\sqrt{CD}$.

If the heights of the cones, or the distances between the points of suspension and the centres of the planes of revolution, be the same, the periodic times, or the times of revolution, will be the same, whatever may be the radii of the circles described by the revolving bodies. This will be clearly understood by contemplating the subjoined diagram, *fig.* 29., where all the pendulums C *a*, C *b*, C *c*, C *d*, and C *e*, having the common axis CD, will revolve in the same time; and if they are all in the same vertical plane when first put in motion, they will continue to revolve in that plane, whatever be the velocity, so long as the common axis or height of the cone remains the same. This will become manifest, if we conceive an inflexible bar or rod of iron to pass though the centres of all the balls as well as the common axis, for then the bar and the several balls must all revolve in the same time; but if any one of them should be allowed to rise higher, its velocity would be increased, and if it descends the velocity will be decreased.

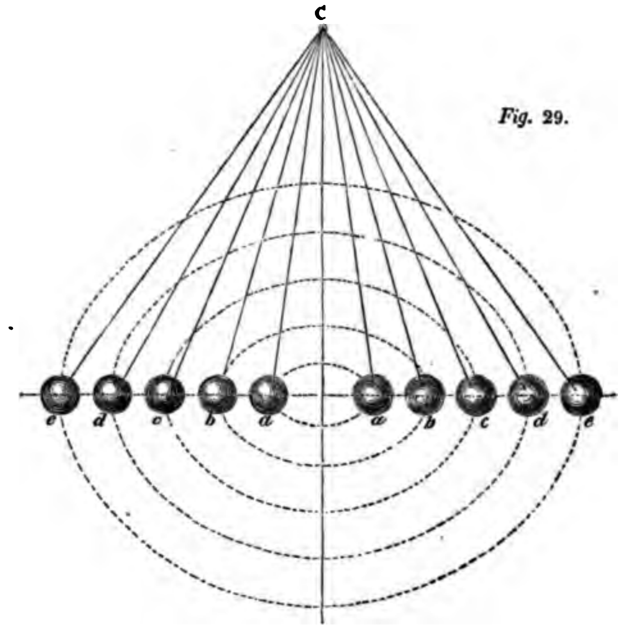


Fig. 29.

Half the periodic time of a conical pendulum is equal to the time of vibration of a simple pendulum, the length of which is equal to the axis or height of the cone; that is, the simple pendulum makes two oscillations or vibrations from side to side, or it arrives at the same point from which it departed, in the same time that the conical pendulum revolves about its axis. The space descended by a falling body in the time of one revolution of the conical pendulum is equal to $3{\cdot}1416^2$ multiplied by twice the height or axis of the cone. The periodic time, or the time of one revolution, is equal to the product of $3{\cdot}1416\sqrt{2}$ multiplied by the time of falling through the height of the cone. The weight of a conical pendulum, when revolving in the circumference of a circle, bears the same proportion to the centrifugal force, or its tendency to fly off in a straight line, as the axis or height of the cone bears to the radius of the plane of revolution; consequently, when the height of the cone is equal to the radius of its base, the centripetal or centrifugal force is equal to the power of gravity.

These are the principles on which the action of the conical pendulum depends; but as we shall hereafter have occasion to consider it more at large, we need not say more respecting it in this place: before dismissing the subject, however, it may be proper to put the reader in possession of the rules for calculating the position of the centre of oscillation in vibrating bodies, in a few cases where it has been determined, these being the cases that are of the most frequent occurrence in practice.

The *centre of oscillation* in a vibrating body is that point in the line of suspension, in which, if all the matter of the system were collected, any force applied there would generate the same angular motion in a given time as the same force applied at the centre of gravity. The centres of oscillation for several figures of very frequent use, suspended from their vertices and vibrating flatwise, are as follow:—

In a right line, or parallelogram, or a cylinder of very small diameter, the centre of oscillation is at two-thirds of the length from the point of suspension. In an isosceles triangle the centre of oscillation is at three-fourths of the altitude. In a circle it is five-fourths of the radius. In the common parabola it is five-sevenths of its altitude. In a parabola of any order it is $\left(\frac{2n+1}{3n+1}\right) \times$ altitude where n denotes the order of the figure.

In bodies vibrating laterally, or in their own plane, the centres of oscillation are situated as follows; namely, in a circle the centre of oscillation is at three-fourths of the diameter; in a rectangle, suspended at one of its angles, it is at two-thirds of the diagonal; in a parabola, suspended by the vertex, it is five-sevenths of the axis, increased by one-third of the parameter; in a parabola, suspended by the middle of its base, it is four-sevenths of the axis, increased by half the parameter; in the sector of a circle it is three times the arc of the sector multiplied by the radius, and divided by four times the chord; in a right cone it is four-fifths of the axis or height, increased by the quotient that arises when the square of the radius of the base is divided by five times the height; in a globe or sphere it is the radius of the sphere, plus the length of the thread by which it is suspended, plus the quotient that arises when twice the square of the radius is divided by five times the sum of the radius and the length of the suspending thread.

In all these cases the distance is estimated from the point of suspension, and since the centres of oscillation and percussion are in one and the same point, whatever has been said of the one is equally true of the other.

HEAT AND COMBUSTION.

Having now explained at some length the mechanical principles with which the student of the steam engine ought to be acquainted if he wishes to get to the bottom of the subject, we shall next say something of the nature of heat and combustion, an acquaintance with which is equally necessary to his proficiency. Upon some, we are aware, these elementary elucidations will be thrown away, for the greater number of competent engineers are already familiar with such inquiries; and it is not to be supposed that we can add materially to their information upon these preliminary topics. But to a far larger number a treatise upon the steam engine would be a sealed book without such steps of easy progression; and our profession is, while aspiring to add to the information of the initiated, to open the subject of the steam engine up to those unacquainted with steam, or any other science.

There are three modifications of heat of which philosophers speak; sensible heat, latent heat, and specific heat. *Sensible* heat is the heat which is observable by the thermometer, or discoverable by the senses; and this kind of heat exists in every thing with which we are acquainted; for, as we know of nothing so cold but what it might be colder, there is nothing without a certain degree of heat in the whole range of our experience. The frosty atmosphere of our own climate, for example, is not so cold as that of Russia, while the Russian atmosphere, again, is more genial than that of the north pole; and even at the north pole some times are colder than others, and as cold arises merely from a penury of heat, there are variations in the degrees of heat even in the coldest situations, and consequently *some* existing and discoverable by the thermometer in all things.

Latent heat is defined to be that heat which is not discoverable by the thermometer, but is expended in producing a change of state, as in the liquefaction of ice or the vaporization of water. If an open vessel of water be placed upon a fire, the temperature of the water will not rise above the boiling point, or 212 degrees, however long the boiling be continued, although the water must have been all the while receiving accessions of heat from the fire. All the heat received over and above that requisite to produce the temperature of 212° is expended in the formation of steam, but the steam itself does not rise above 212°; and on account of the heat thus hiding itself, as it were, in the steam, it is called latent heat. The term, however, is a bad one, as the obvious explanation is, that heat is capable of producing two distinct effects; the one an elevation of temperature with the same volume, and the other an augmentation of volume with the same temperature; and these effects are equivalent and convertible. There is, therefore, no more propriety in saying that heat is latent when it does not elevate the temperature of a body than when it does not enlarge its volume, for in each case the effect proper to the application is produced, and to look for an augmentation of temperature, as well as an augmentation of volume, would be to reckon upon receiving the same thing twice over.

The latent heat of steam is said to be 1000°, which means that it would take 1000 times more heat to raise a pound of water into steam than to raise it one degree in temperature, or what is the same thing, the heat required to raise a pound of water into steam would raise 1000 pounds of water one degree. From this it appears that it requires about 5½ times as much heat to raise any given weight of water into steam as would raise the same weight of water from the freezing to the boiling point. The freezing point is 32°, and the boiling point 212°, so that the amount of difference, or the number of degrees through which the temperature has to be raised between the freezing and boiling points, is 180°, and 180° multiplied by 5½ is 990, or 1000 nearly.

Specific heat means the quantity of heat contained by one body at a given temperature compared with the quantity contained in another body at the same temperature. It by no means follows that the same weights of different bodies at the same temperature contain the same quantities of heat, any more than that the same bulks of different bodies contain the same quantities of matter, and the specific heat of a body indicates the quantity of heat it contains just as its specific gravity indicates its quantity of matter. The specific heats of a great number of bodies have been ascertained and arranged in tables just as their specific gravities, and the specific heat of water is taken as unity.

A great deal of confusion has been cast over the subject of specific heat by the accredited definition of latent heat, which is said to be the heat absorbed by bodies during a change of state from solid to liquid, and from liquid to aeriform, whereas it ought to be the heat absorbed without elevation of temperature, whether there be a change of state or not. From the want of this stipulation, the heat produced by the compression of air, or the cold produced by its dilatation, has been ascribed to a change in the specific heat of the air, while the change of temperature due to a corresponding operation in the case of steam is set down as being due to a change in the latent heat. From the experiments of Watt and others, it appears that the sum of the latent and sensible heats of steam is a constant quantity very nearly; so that when steam is expanded, its latent heat is increased in about the same ratio in which its temperature is diminished; yet as there has been no change of state in the case of air, the depression of its temperature during expansion is charged upon its specific heat, although that element is in reality guiltless of the transformation. We have thus the anomaly of that being reckoned specific heat in one country which is counted latent heat in another, for the steams of one climate are the gases of a warmer one; and if the same laws respecting latent and specific heat be not suffered to hold in the case of air, as in that of steam, the conditions of latent and specific heats resolve themselves into mere questions of latitude and longitude. Ether, which exists in the liquid form at the ordinary atmospheric temperatures of this country, becomes a permanent gas at the equator; and many substances which exist in the liquid state at Geneva become aeriform at the summit of Mount Blanc; and the only way to escape from the inconsistencies involved by the present doctrines on this subject is either to depose the steams from the position they now hold and set them upon the same ground the airs occupy, or, what, in our judgment, is better still, because opening a road connecting theory with experiment, to accept the definition we have indicated. The way in which this connection is to be made we shall now endeavour to show.

It may not be known to some of our readers that all bodies are supposed to be built up of indefinitely small molecules of matter called atoms; and indeed, if it be admitted that there is such a thing as matter at all, it may be now taken for granted that it is thus constituted. These atoms are never broken up into fragments, but when bodies combine, a certain number of the atoms of the one mingle with a certain number of the atoms of the other, rejecting any excess of either that may be offered beyond the proportions proper to the compound, and this is what is understood by combining in definite or atomic proportions. Messrs. Dulong and Petit, from a number of considerations, have been led to believe that the specific heats of bodies are inversely as their atomic weights, or in other words that each atom of a body has the same quantity of heat, so that its specific heat will be great in the proportion in which the weight of its atoms is small, and consequently the greater number of atoms in it. The experiments, however, of these ingenious inquirers did not bear out this view of the case; but the discrepancy arises, in our belief, from the admission of a certain proportion of latent heat as an element of the investigation, so that the heat indicated, instead of being the true specific heat, is a compound quantity made up of latent and specific heats conjointly. In ascertaining the specific heat of iron, for example, the plan adopted was to heat the iron to a certain temperature, and plunge it into a vessel of water of which the temperature was known, and the rise in the temperature of the water was supposed to indicate the specific heat of the metal. But it is obvious that a contraction of the iron would take place when plunged in the water, the heat due to which would by its extrication go to increase the temperature of the water, and thus vitiate the result. If the amount of this heat were to be ascertained, and subtracted from Dulong and Petit's results, we have every confidence that the numbers obtained would then bear out their very ingenious hypothesis; and which from other considerations has the strongest probability to support it. And if the specific heats of bodies vary inversely as their atomic weights, it is plain that they cannot vary with the temperature, provided heat be imponderable; for the weight of a body is made up of the weight of the atoms of which it is composed, and an atom cannot be heavier if the body be not heavier itself. If, therefore, the weights of the atoms be unaffected by temperature, and a fixed relation exists between the weights of the atoms and the specific heats, the specific heats cannot be affected by temperature either, and the specific heat of a body must be the same whether it be in the solid, liquid, or aeriform state, so that the specific heat of the same body remains unchanged under all its transmutations. This conclusion does not correspond exactly with experiment, for the specific heat of steam, for example, is rated at ·847, that of water being 1. But there are very few of the experiments on the specific heats of aeriform bodies, upon which much dependence can be placed; as the investigation is one of infinite difficulty, from the delicacy required in the manipulation, and the minuteness of the result that is to be caught.

NATURE OF HEAT.

There are two theories in the field respecting the nature of heat: the one regards it as a material substance, and the other as a mere undulatory motion in the molecules of bodies, or in a highly elastic and subtle fluid which pervades all space, and which is capable of transmitting vibrations. As philosophers still differ upon this subject, it is not to be supposed that we shall perplex ourselves with it, especially as engines will work equally well whatever theory be the correct one. The inquiry, however, is not without interest, as, if the doubt were resolved, we should perhaps have such light thrown upon the modes of exciting heat as might greatly conduce to economy in steam machinery, and at least we should then be able to construct furnaces more scientifically. If heat be a material substance and not a mere quality of matter, the heat produced by the combustion of a given quantity of fuel in the internal furnace of a steam boiler must either enter the water, or escape up the chimney, and in this case the indication would be to make the combustion very slow, in order that it may be the more perfect: but, if heat be merely a vibratory motion in the particles of bodies, slow combustion may be carried too far, and it may become then an indication to cause the heat to be absorbed as near as possible to the spot in which it is excited, for the vibratory motions may otherwise become faint or altogether cease without producing any adequate effect upon the water in the boiler.

COMBUSTION.

Combustion is nothing more than a vehement combination of the constituents of coal with the oxygen of the atmosphere, and which only takes place at a high temperature. In all cases of chemical combination there is a transfer of electricity, and it is essential to combination that the combining bodies shall be in opposite electrical states. The rusting, or, as it is more learnedly termed, the oxydation of iron, is caused by the combination of the oxygen of the atmosphere therewith, and is therefore a process analogous to the combustion of coke or cinders, which might be described as the rapid rusting of carbon.

To maintain this rapidity of oxydation, it is indispensable that the air be quickly renewed, and hence the necessity in a furnace for the existence of a draught. The atmosphere consists of a mixture of two gases, oxygen and nitrogen or azote, in the proportion of 1 volume of the former to 4 of the latter. The specific gravity of oxygen is 1·111, that of air being unity; and the specific gravity of nitrogen is ·9722. Coal consists of charcoal or carbon united with hydrogen and other gases in very variable quantity in the different kinds of coal, and intermingled with sulphur and other impurities. The most flaming kind of coal is that which contains most hydrogen, whereas anthracite and coke contain little or none, and the earthy matter present in coal takes during combustion the form of ashes. 1000 lbs. of splint coal contains, according to Dr. Thomson, 647·3 lbs. of coke and 352·7 lbs. of volatile matter, while cannel coal contains in the same weight only 400 lbs of coke, and as much as 600 lbs. of volatile matter. Cannel coal, however, is not used in furnaces, so that we need not consider its peculiarities, nor is the splint coal now much used for the generation of steam, except in a few situations, for, although very effectual, it burns quickly away, and is not the most economical, except near the places at which it is dug. The Welsh coal appears to be the best adapted for the generation of steam with economy, and it consists chiefly of carbon, and has very little hydrogen in it. The combination of oxygen with carbon forms carbonic acid, and during the conversion the gas does not undergo any change of volume but only increases in density. The specific gravity of carbonic acid is 1·5277, so that a pound and a half of carbonic acid has half a pound of carbon in it, or in other words, every pound of coke or Welsh coal requires about two pounds of oxygen for its saturation. But the oxygen is mingled with nitrogen, from which it cannot detach itself, and for every two pounds of oxygen that enters into combination, seven pounds of nitrogen must pass through the fire, making a total of nine pounds of atmospheric air to every pound of coal, supposing that all the oxygen enters into combination. But this is never the case, and in the great majority of fires eleven or twelve pounds of atmospheric air will be required for the combustion of a single pound of coal, at the lowest computation, and sometimes the quantity much exceeds this amount.

Smoke is the product of the imperfect combustion of bituminous coal, caused either by a want of oxygen or a want of temperature. If analysed, it will be found to consist of uncombined carbon, carbonic acid and carbonic oxide, aqueous vapour, bituminous vapour, and the other volatile products of coal, nitrogen and atmospheric air, in varying proportions. There is often an intermixture, too, of sulphur, ammonia, and probably of cyanogen. In common language, a furnace is said to burn without smoke when no uncombined carbon is visible at the chimney; but even in such cases there may be a great waste of combustible material, by the formation of carbonic oxide in the furnace, which may be defined to be invisible smoke, and which may carry a large amount of carbon, which would otherwise have been productive of benefit, into the atmosphere.

Flame may be defined to be aeriform or gaseous matter heated to such a degree as to be luminous, and may be produced independent of any chemical change, as is shown in the discharge of voltaic electricity through an undecomposable gas. When flame is produced in chemical combinations, gaseous matter is always the cause of it. In the flame of solid substances which contain carbon, such as coal, wax, &c., three effects are observable on the application of heat, 1st, — Volatilization; 2nd, Decomposition; 3rd, Ignition. Thus, in the flame of a candle the wax is first volatilized, being converted by the heat into vapour; this vapour by reason of its specific levity ascends into the body of the flame, where it is decomposed, carbon is separated, and that carbon by its ignition is the chief cause of the light. Thus the brilliancy of coal gas increases with the quantity of carbon entering into its composition, and the flame of the oxyhydrogen blow-pipe, where the heat is the most intense that has hitherto been produced, is almost invisible.

If air be admitted to a candle in deficient quantity it will smoke, because the oxygen will be monopolised by the hydrogen of the flame, and the carbon must then be thrown off in the form of soot. If the temperature of the flame of a candle be artificially lowered it will smoke, because after vaporization and decomposition, not heat enough is left to effect the ignition of the carbon. Thus, if a candle be left with a long wick, so much heat is given off from it by radiation that the candle smokes. If the point of a pair of snuffers or any other cold body be introduced into the flame, smoke is produced by the diminution of temperature; or if a small tin pan containing water be held over the flame, the bottom of the pan will soon be covered with soot, on account of the heat absorbed by the water. The same thing may be shown more strikingly by means of a piece of wire gauze; if this be held in the very base of the flame, no carbon will be deposited on it, for decomposition has not yet commenced there; if it be held in the middle of the flame it will soon be covered with soot, on account of its cooling action preventing the ignition of the carbon resulting from decomposition; but if it be held again at the apex of the flame, no carbon will be deposited, for before the particles ascend so high, they have been ignited and converted into carbonic acid by uniting with the oxygen of the atmosphere. These examples will illustrate the action of a common furnace, in which, if after the decomposition of the gas in the coal there ceases to be a sufficiency of oxygen to form carbonic acid with the carbon of the gas, there must be a production of smoke, when bituminous coal is burned, whatever the temperature of the furnace may be; for carbon has never yet been vaporized, or even fused.

When an inflammable gas is mixed with an uninflammable gas in certain proportions, the mixture will not take fire, and cannot be exploded by the electric spark. The effect is similar to what would be produced by mixing water with oil, and the cause of the phenomenon is the same—the cooling agency of the incombustible substance. Thus the various incombustible gases have different degrees of power to prevent explosion or combustion according to their densities, or, in other words, according to their cooling powers. The efficacy of carbonic acid and nitrogen, and of the surfaces of small tubes, or of the wire gauze of the safety lamp, in preventing explosions in coal mines, arises from the refrigeration accomplished by those substances upon the exploding mixture, so that the temperature is no longer sufficient for its continuous inflammation. By mixing one part of carbonic acid with seven parts of an explosive mixture of carburetted hydrogen and atmospheric air, or one part of nitrogen with six parts at the common atmospheric temperatures, the explosive powers of the mixture are destroyed. At the high temperature of a furnace the gases not concerned in combustion will have less power in preventing that operation; and it is found that steam and vapours which require a considerable heat for their formation will have less effect in preventing combustion than gases at the common heat of the atmosphere. It requires a very large quantity of steam to prevent sulphur from burning. Oxygen and hydrogen explode by the electric spark when mixed with five times their bulk of steam; and even a mixture of air and carburetted hydrogen, the least explosive of all mixtures, requires a third of steam to prevent its inflammation.

By an experiment of Rumford's, it appears that all bodies, whatever the activity of their inflammation may be, may be extinguished by cooling agency. Even the explosion of gunpowder may be thus arrested, and its incipient inflammation be extinguished by directing on it a strong blast of air. When we blow out a candle, we are indebted to the cooling agency of a blast of air for the success of the operation. A very simple and elegant illustration of the effect of cold in extinguishing flame may here be stated, and is as follows:—Let the smallest possible flame be made by a single thread of cotton immersed in oil; it will be found to be about one thirtieth of an inch in diameter. Let a fine iron wire of one one hundred and eightieth be made into a circle of one tenth of an inch in diameter, and brought over the flame. Though at such a distance, it will instantly extinguish it if *cold*: but if it be held over the flame so as to be slightly heated, the flame may be passed through it. That the effect depends entirely upon the power of the metal to abstract the heat of the flame, is shown by bringing a glass capillary ring of the same diameter and size over the flame. This being a much worse conductor of heat, will not extinguish it even when *cold*. If its size, however, be made greater, and its circumference smaller, it will act like the metallic wire, and require to be heated to prevent it from extinguishing the flame. Another similar experiment may be made by bringing a small metallic ball near a very small flame. If the ball be cold, or even if it be red hot, it will extinguish the flame, but if brought to a state of ignition, it will then cease to produce the effect.

Different degrees of heat inflame the different combustible gases resulting from the distillation of coal. Carburetted hydrogen mixed with air is not ignited by well burned charcoal ignited to the strongest red heat. Indeed, a fire made of well burned charcoal, that is, charcoal that will burn without flame, may be blown up to whiteness by an explosive mixture consisting of air and carburetted hydrogen. An iron rod at the highest degree of red heat, and at the common degree of white heat, will not inflame such a mixture, but when in brilliant combustion it will produce the effect. The flame of carbonic oxide will inflame an explosive mixture of air and carburetted hydrogen. Olefiant gas and carbonic oxide may both be inflamed by iron heated to redness or by charcoal; and hydrogen, which explodes when mixed with three sevenths of its volume of air, takes fire at the lowest visible heat of iron and charcoal, and the case is the same with sulphuretted hydrogen. Atmospherical air, when very considerably rarefied, is rendered unfit for supporting combustion. This fact was known to the earlier experimenters upon the Boylean vacuum, but the subject remained involved in considerable obscurity until investigated by Sir H. Davy. He has shown that flame ceases in rarefied air, not from a want of nourishment, but from want of heat, and that if its temperature could be preserved by some supplementary aid it might be kept burning. It is not, however, by the same degree of rarefaction of air that the combustion of all bodies is suspended, for, as might naturally be supposed, those which require least heat for their combustion burn in more rarefied air than those which require a higher temperature; and again, those that produce much heat by their combustion burn in more rarefied air than those which evolve little heat. The following table shows the degrees of rarefaction of common air at which the combustion of some inflammable bodies ceases, both with and without the appendage of a coil of platinum wire.

	Without Platinum.	With Platinum.	
Olefiant gas ceases to burn in air rarefied	- -	- 11 to 12	times
Carburetted hydrogen - - - -	- -	- 4	—
Carbonic oxide - - - - -	- -	- 6	—
Alcohol Wax taper - - - - -	5 to 6	- 7 to 8	—
Sulphuretted hydrogen - - -	7		—
Sulphur - - - - - -	15 to 20	-	—
Phosphorus - - - - -	60	-	—

By preserving heat in rarefied air the inflammation of bodies may be continued, when under other circumstances it would have beeu extinguished. Thus when camphor is burned in a glass tube, so as to make the upper part of the tube red hot, the inflammation continues even when the rarefaction is nine times; whereas it will only continue in air rarefied six times when the camphor is burned in a thick metallic tube, which cannot be considerably heated by it. The mechanical condensation of air does not adapt it for supporting a more vivid combustion. If air be condensed five times, and then iron wire be ignited to whiteness within it by the voltaic apparatus, the combustion will go on with very little more brightness than in the common atmosphere, and will not continue, as in oxygen. Charcoal, again, will not burn much more brightly in this compressed air than in common air; and indeed the whole of our experience goes to show that compression of the air does not increase the vehemenee of combustion, provided always the air be kept stationary and be not used as a blast.

From the experiments of Despretz* it does not appear that the quantity of heat given out by charcoal during combustion is greater or less in condensed oxygen gas than in gas of the common density; and he is of opinion that the same uniformity would be found to obtain in the combustion of sulphur and other bodies which burn in oxygen without a change of volume.

If we knew the precise nature and quantity of the combustible matters in smoke, and the temperature of the smoke as it emerges from the furnace, we could, by a very simple calculation, tell what would be the amount of advantage or disadvantage resulting from the admission of a sufficiency of air to perfect the combustion, supposing the cooling agency of the boiler to be absent. But in all practical cases, this is a quantity which must be considered, the combustion of smoke being of diminished importance when the heat generated is not absorbed by the boiler; and when the heat is so absorbed, the effect is to extinguish the flame, in a way similar to that in which the ring of wire operated on the small flame of a lamp in one of the experiments we have recited. If the flame resulting from the combustion of the smoke does not act upon the boiler, no calorific effect can of course be obtained from it, and there will be an increased consumption of fuel. When it does impinge upon the boiler, there is a danger that the cooling agency of the boiler, when conjoined with that of the nitrogen, carbonic acid, and cold air, will so diminish the temperature that the flame will be extinguished.

It has been already mentioned that one part of nitrogen, when mixed with six parts of an explosive mixture of carburetted hydrogen, or one part of carbonic acid with seven parts, destroys at common temperatures, the combustibility of the mixture. These proportions will of course be very much altered at the temperature at which smoke emerges from a furnace; but even in that case, the temperature of the smoke is so much beneath that of visible flame, that the effect of the nitrogen and carbonic acid will necessarily exert a powerful influence; and the difficulty of consuming or obviating smoke is greatly increased, or rather, we should say, altogether caused, by the presence of these gases. The combustion of smoke, however, is by no means impossible, notwithstanding these impediments, and in large towns the smoke nuisance has risen to so intolerable a pitch that its suppression we look upon as being now inevitable. During the last year a parliamentary committee has carefully investigated the means by which smoke may be done away, and has recommended that a bill be brought into parliament for the suppression of the nuisance. In this recommendation we cordially concur; for there is nothing of which we are more confident than that manufacturers and others would very quickly find out means of obviating the smoke emitted by their factories if it were made penal to produce any. Of the prevention of smoke in the case of house fires we are by no means equally sanguine; and indeed the expense of new grates or other machinery in all the fire-places of a great city would be a serious barrier to the introduction of such an improvement, even if it were known to be feasible. But in the case of furnaces, and other close fires, we have no such doubts; and as the question of smoke-prevention forms not only a part of the general subject we have undertaken to discuss, but is of great interest at the present moment to almost every member of the community, we shall here introduce such remarks upon the subject as, without leading us into any practical details, will indicate some of the modes in which the desired innovation may be accomplished.

The whole of the smoke-burning furnaces that have been hitherto projected may be classed roughly under two general heads. In the one the smoke is burned by passing through, over, and among the burning fuel; and in the other it is consûmed by the admission of a stream of air at the bridge, or in some other part, to mix with and consume the smoke after it has left the fire. It is necessary, indeed, in all cases of the combustion or smoke, that air should be present; for carbon, by which the colour of smoke is imparted, cannot be fused or dissipated in any way within a furnace without oxygen; but in some cases the oxygen already mixed with the smoke is sufficient for its combustion; and all that is wanted in such a case is its subjection to an elevated temperature. Papin proposed to consume smoke by causing the draught to pass down through a fire, and this draught might be maintained by means of his cylindrical blower or fan. This scheme was in part revived by Franklin, who contrived a stove for burning its own smoke in which the air descended through the fuel. Watt employed in his early trials a hopper through which a current of air was solicited to descend; but he found this difficult to manage, in consequence of the caking of the coal; and he in consequence relinquished the plan in favour of a dead plate at the mouth of the furnace, which when conjoined with a slow combustion and careful firing, is found to be very effectual. The raw coal is first placed upon this dead plate, upon its introduction to the furnace; and the smoke and gases proceeding from the coal on the application of heat are consumed in passing over the incandescent fuel. In some cases, air is admitted at the furnace door, and in other cases not, the alternative being contingent upon the rapidity of the draught and the thickness of the stratum of fuel maintained on the fire bars; for when the draught is quick and the fire thin, enough uncombined oxygen will escape up through the fuel to accomplish the inflammation of the combustible parts of the smoke. The coal in this plan has to be pushed back from the dead plate into the active part of the furnace as soon as its gases have been expelled: an operation attended with more trouble than the ordinary method of firing, and therefore very generally neglected.

The method of admitting air, either at the bridge or in some situation beyond it, in order to accomplish the combustion of the smoke, is, in the case of furnaces unprovided with any feeding mechanism, attended with the very obvious objection that it is a thing impossible duly to apportion the admission of the air to the varying wants of the fire; so that there will generallly be either too little air gaining admittance, or too much — in the latter case not merely interfering with the combustion of the smoke, but seriously cooling the boiler. With very careful and *scientific* firing, indeed such as an experiment may obtain, the smoke is found to be very effectually obviated by the admission of air, and a saving in fuel to the extent of 12 or 14 per cent. may be realised; but under the average circumstances of firing there is no gain by the admission of air, but rather a loss; and the plan, therefore, though often revived, and sometimes under very imposing names, by successive projectors, has never been brought into extended practice. It is only in cases where self-acting fire-feeders are employed. that the plan of burning smoke by an admission of air into the flue is at all applicable; for there the production of smoke being nearly uniform, the air orifice may be adjusted with much nicety to its requirements, and needs no subsequent alteration. Even under this modification, however, we do not look upon the plan for consuming smoke by admitting air at the bridge or in the flues as the best that is available; and the addition of fire-feeding mechanisms would be a heavy expense as a preliminary condition, and could not be applied to existing boilers in all cases.

We reserve for the practical part of this treatise any thing that we may have to say respecting the merits of the rival smoke-burning schemes that have latterly contended with one another for the countenance of the public: but we would here desire to explain, that the method by which the nuisance of smoke might in the most difficult cases, as in steam-vessels, be most easily and effectually obviated, lies, in our apprehension, in leading the smoke without any new intermixture through a perforated fire-brick bridge, which would answer very nearly the same purpose as a second fire. This bridge, however, to be effectual, would require to be of a considerable length, and should have several breaks in it, so as to agitate the smoke in its passage; but at the same time it should be so made as to be capable of being easily cleared, for a crust of ashes will be found to form upon the fire-brick surface, which will require to be swept away occasionally. The depth of fire upon the bars, and the intensity of the draught, must of course be so regulated, that air enough will ascend through the fire to accomplish the combustion of the smoke, and it is important that the fire be fed often and in small quantities at a time. But if the smoke be agitated when in a hot state and at the same time the ordinary excess of oxygen be present, the carbonaceous portion of the smoke will be burned very effectually. Furnaces will generally cease to smoke when a very bad back-draught comes upon them, as the agitation of the air in that case facilitates the combination of the combustible parts of the smoke, with its intermingled oxygen; and in an air furnace for melting iron. where the smoke is deflected down upon the hot metal, all appearance of carbon ceases when the furnace has reached an elevated temperature. Nor is this owing, in the cases to which we allude, to the formation of carbonic oxide, but arises merely from the combustion of the smoke in consequence of the agitation it undergoes on the flame

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* 37 Ann. de Ch. et de Ph 182.

bed, and the high temperature to which it is subjected. It would no doubt greatly facilitate the burning of smoke in furnaces generally if the heat were prevented from entering the water of the boiler by a fire-brick casing, or some other such means, until after the smoke had been consumed, for the temperature thus retained would much facilitate combustion. But it is not certain that a loss of effect would not result from this innovation, though if the heat producible by a unit of coal be a constant quantity, and cannot cease to exist without producing a corresponding effect upon other bodies, it is difficult to see in what way a loss of effect is possible. In that case any heat the coal produced would necessarily enter the water if it did not escape at the chimney, and if less heat were communicated by the furnace, a proportionably greater amount would be communicated by the flues; but the subject is involved in too much obscurity to give worth to any hypothesis, and we have as yet no experiments upon this point that are adequate to resolve our doubts.

A good deal of interest has been at various times excited by the peculiar formation of the Cornish boiler; one property of which is, that it generates steam with very little smoke, as well as with considerable economy of fuel. This result is usually attributed to slow combustion; and certainly a most important thing in the design of any measures for the combustion of smoke is to give as much time as can be afforded for accomplishing the combination, as well as to make the intermingled gases as homogeneous as possible. A large part of the smokeless virtue of the Cornish boilers, however, is to be attributed to the nature of the coal usually employed there, which contains very little hydrogen; and consequently only a small proportion of that bituminous material out of which smoke is formed. These circumstances, whatever be their several values, certainly, when taken together, go to produce a very satisfactory result; and in boilers operating on the Cornish plan, and with the Cornish, or rather the Welsh fuel, an almost inappreciable quantity of smoke is generated. Several of these boilers have of late years been set up in London, and furnish certainly a strange contrast to the vehement smoking of the ordinary metropolitan fires. Of these the boilers employed for driving the machinery of Mr. Thomas Cubitt's factory, at Vauxhall Bridge, has probably attracted the most attention; and no one, indeed, looking to the small quantity of smoke which escapes from that monumental chimney, could imagine that there was a boiler of any kind in that situation. The necessity of using Welsh coal, however, to produce this result, is certainly an objection in the case of London furnaces, for Welch is dearer than Newcastle coal in the metropolis; yet this extra expense is but a small consideration when put against the inconvenience and insalubrity caused by smoke in large cities, and it should, we think, be made imperative that those who do not feel disposed to dispatch their smoke by any other method should use the Welsh or some other smokeless coal, so that they may cease to be with impunity manufacturers of a nuisance. The greatest manufacturers of smoke, however, in London, are the brewers, distillers, and chemical manufacturers, to whose operations the expedients of the Cornish boiler will probably not apply. But there will very soon be discovered expedients that will apply in every case if the production of smoke be only made punishable. Those who cry out the most loudly against the hardship of being compelled to extinguish a nuisance which is not known to be susceptible of abatement, are in most cases conscious all the while that the prevention of smoke is possible, though it at first might be attended with some trouble, and they will be very quick in finding a remedy when their works are prohibited against going on upon any other condition.

THE TEMPERATURE AND ELASTIC FORCE OF STEAM.

Steam, as all our readers know, is an elastic fluid generated from water by the application of heat. It is, in fact, water in a high state of rarefaction, or so impregnated with caloric, or the matter of heat, as to assume the state of an aëriform or elastic fluid. When steam is confined in a close vessel in contact with the water that produces it, the effort by which it endeavours to expand itself and enlarge its volume, or to separate the parts of the vessel that confines it and set itself free, is called the *elastic force* of steam. In estimating the mechanical action of steam, the intensity of its elastic force must be referred to some known standard measure, such as the pressure which it exerts against a square inch of the surface that contains it, usually reckoned by so many pounds avoirdupois upon the square inch. The intensity of the elastic force is also estimated by the inches in height of a vertical column of mercury, whose weight is equal to the pressure exerted by the steam on a surface equal to the base of the mercurial column. It may also be estimated by the height of a vertical column of water measured in feet; or generally, the elastic force of any fluid may be compared with that of atmospheric air when in its usual state of temperature and density: this is equal to a column of mercury 30 inches or 2½ feet in height.

When the temperature of steam is increased, respect being had to its density, the elastic force, or the effort to separate the parts of the containing vessel and occupy a larger space, is also increased; and when the temperature is diminished, a corresponding and proportionate diminution takes place in the intensity of the emancipating effort or elastic power. It consequently follows that there must be some law or principle connecting the temperature of steam with its elastic force; and an intimate acquaintance with this law, in so far as it is known, must be of the greatest importance in all our researches respecting the theory and the mechanical operations of the *steam engine*. The precise form of the expression which expounds the true mathematical law or principle of elasticity, has never yet been rigorously ascertained, but recent investigations have put us in possession of numerous empirical forms, by which the results of several classes of very delicate and valuable experiments are represented with a sufficient degree of exactitude to answer all the demands of practice. These forms we mean to compare with one another, in order to deduce an expression that may best represent the average results obtained, and may at the same time be easily applicable to the uses of the practical engineer.

It is not our intention, however, nor would it be consistent with the plan of our performance, to trace the steps of investigation by which these multitudinous formulæ have been elicited; but we may state that the general mode of procedure is by reference to a curve of such a nature, that the co-ordinates are respectively indicated by the temperature of the steam, and the corresponding elastic force. This curve will be variously expounded according to the manner in which it is considered, but in every case, the exponent expressing the order or degree of the curve, is that which indicates the law of elasticity, and is that only whose value can be expressed by a legitimate formula. The other constants or coefficients by which the equations are affected, having their values depending on some gratuitous conditions, are beyond the powers of a direct analysis, and are, therefore, only deducible by some indirect process of approximation or trial and error, a mode of procedure often resorted to by analysts in reducing expressions of a complex and intricate character. But notwithstanding that it is foreign to our plan to enter into long and elaborate dissertations respecting the dilatation and compression of elastic fluids, we should yet consider our labours as being very imperfect, did we not, in one instance at least, lay before our readers the method of detecting the law of elasticity; and in order that the process may be the more easily understood, we shall previously resolve the following very elegant and useful problem:—*To find a theorem, by means of which it may be ascertained when a general law exists, and to determine what that law is, in cases where it is known to obtain.*

Suppose, for example, that it is required to assign the nature of the law that subsists between the temperature of steam and its elastic force, on the supposition that the elasticity is proportional to some power of the temperature, and unaffected by any other constant or coefficient, except the exponent by which the law is indicated. Let E and e be any two values of the elasticity, and T, t, the corresponding temperatures deduced from observation. It is proposed to ascertain the powers of T and t, to which E and e are respectively proportional. Let n denote the index or exponent of the required power; then by the conditions of the problem admitting that a law exists, we get, $T^n : t^n :: E : e$; but by the principles of proportion, it is $\frac{t^n}{T^n} = \frac{e}{E}$; and if this be expressed logarithmically, it is $n \times \log. \frac{t}{T} = \log. \frac{e}{E}$, and by reducing the equation in respect of n, it finally becomes

$$n = \frac{\log. e - \log. E}{\log. t - \log. T}.$$

The theorem that we have here obtained is in its form sufficiently simple for practical application; it is of frequent occurrence in physical science, but especially so in inquiries respecting the motion of bodies moving in air and other resisting media; and it is even applicable to the determination of the planetary motions themselves. The process indicated by it in the case that we have chosen, is simply, *To divide the difference of the logarithms of the elasticities by the difference of the logarithms of the corresponding temperatures, and the quotient will express that power of the temperature to which the elasticity is proportional.*

Take as an example the following data:—In two experiments conducted by Mr. Southern, with his customary attention to accuracy, it was found that when the temperature of steam was 250·3 and 343·6 degrees of Fahrenheit's scale, the corresponding elastic forces were 59·6 and 238·4 inches of the mercurial column respectively. From these data it is required to determine the law which connects the temperature with the elastic force on the supposition that a law does actually exist under the specified conditions. The process by the rule is as follows:—

Greater temperature, 343·6 - - - -	log. 2·5352941
Lesser temperature, 250·3 - - - -	log. 2·3984608
Remainder - - - - - - -	= 0·1368333
Greater elastic force, 238·4 - - - -	log. 2·3773063
Lesser elastic force, 59·6 - - - - -	log. 1·7752463
Remainder - - - - - - - -	= 0·6020600

Let the second of these remainders be divided by the first as directed in the rule, and we get $n = 6020600 \div 1368333 = 4{\cdot}3998$, the exponent sought. Consequently, by taking the nearest unit for the sake of simplicity, we shall have, according to this result, the following analogy, viz.

$$T^{4{\cdot}4} : t^{4{\cdot}4} :: E : e;$$

that is, the elasticities are proportional to the 4.4 power of the temperatures very nearly.

Now this law is rigorously correct as applied to the particular cases that furnished it; for if the two temperatures and one elasticity be given, the other elasticity will be found as indicated by the above analogy; or if the two elasticities and one temperature be given, the other temperature will be found by a similar process. It by no means follows, however, that the principle is general, nor could we venture to affirm that the exponent here obtained will accurately represent the result of any other experiments than those from which it is deduced, whether the temperature be higher or lower than that of boiling water; but this we learn from it, that the index which represents the law of elasticity is of a very high order, and that the general equation, whatever its form may be, must involve other conditions than those which we have assumed in the foregoing investigation. The theorem, however, is valuable to practical men, not only as being applicable to numerous other branches of mechanical inquiry, but as leading directly to the methods by which some of the best rules have been obtained for calculating the elasticity of steam, when in contact with the liquid from which it is generated.

We now proceed to apply our formula to the determination of a general law, or such as will nearly represent the class of experiments on which it rests; and for this purpose we must first assign the limits, and then inquire under what conditions the limitations take place, for by these limitations we must in a great measure be guided in determining the ultimate form of the equation which represents the law of elasticity.

The limits of elasticity will be readily assigned from the following considerations, viz.: in the first place it is obvious that steam cannot exist when the cohesive attraction of the particles is of greater intensity than the repulsive energy of the caloric or matter of heat interposed between them; for in this case, the change from an elastic fluid to a solid may take place without passing through the intermediate stage of liquidity; hence we infer that there must be a temperature at which the elastic force is nothing, and this temperature, whatever may be its value, corresponds to the lower limit of elasticity. The higher limit will be discovered by similar considerations, for it must take place when the density of steam is the same as that of water, which therefore depends on the *modulus of elasticity* of water.[*] Thus, for instance, suppose a given quantity of water to be confined in a close vessel which it exactly fills, and let it be exposed to a high degree of temperature, then it is obvious that in this state no steam would be produced, and the force which is exerted to separate the parts of the vessel is simply the expansive force of compressed water; we therefore have the following proportion. As the expanded volume of water is to the quantity of expansion, so is the modulus of elasticity of water to the elastic force of steam of the same density as water.

Having therefore assigned the limits beyond which the elastic force of steam cannot reach, we shall now proceed to apply the principle of our formula to the determination of the general law which connects the temperature with the elastic force; and for this purpose, in addition to the notation which we have already laid down, let c denote some constant quantity that affects the elasticity, and d the temperature at which the elasticity vanishes; then since this temperature must be applied subtractively, we have from the foregoing principle, $cE = (T - \delta)^n$, and $ce = (t - \delta)^n$. From either of these equations, therefore, the constant quantity c can be determined in terms of the rest when they are known; thus we have $c = \frac{(T - \delta)^n}{E}$, and $c = \frac{(t - \delta)^n}{e}$, and by comparing these two independent values of c, the value of n becomes known; for $\frac{(T - \delta)^n}{E} = \frac{(t - \delta)^n}{e}$, and consequently

$$n = \frac{\log. e - \log. E}{\log. (t - \delta) - \log. (T - \delta).} \quad . \quad . \quad . \quad . \; (A).$$

In this equation the value of the symbol δ is unknown; in order therefore to determine it, we must have another independent expression for the value of n; and in order to this, let the elasticities E and e, become E′ and e' respectively; while the corresponding temperatures T and t assume the values T′ and t'; then by a similar process to the above, we get $\frac{(T' - \delta)^n}{E'} = \frac{(t' - \delta)}{e}$, and

$$n = \frac{\log e' - \log. E'}{\log. (t' - \delta) - \log. (T' - \delta)} \quad . \quad . \quad . \; (B).$$

Let the equations (A) and (B) be compared with each other, and we shall then have an expression involving only the unknown quantity δ, for it must be understood that the several temperatures with their corresponding elasticities are to be deduced from experiment; and in consequence, the law that we derive from them must be strictly empirical; thus we have

$$\frac{\log. e - \log. E}{\log. (t - \delta) - \log. (T - \delta)} = \frac{\log e' - \log. E'}{\log. (t' - \delta) - \log. (T' - \delta)} \quad . \quad . \; (C).$$

We have no direct method of reducing expressions of this sort, and the usual process is therefore by approximation, or by the rule of trial and error, and it is in this way that the value of the quantity δ must be found; and for the purpose of performing the reduction, we shall select four of Mr. Southern's experiments, which in a letter to Mr. Watt he describes as having been performed with great care, and may consequently be considered as representing the law of elasticity with very great nicety. They are as follows: —

$T = 212{\cdot}0^\circ$ Fahrenheit $\quad E = 29{\cdot}8$ inches of mercury.
$t = 250{\cdot}3 \quad e = 59{\cdot}6$
$T' = 293{\cdot}4 \quad E' = 119{\cdot}2$
$t' = 343{\cdot}6 \quad e' = 238{\cdot}4$

Therefore, by substituting these numbers in equation (C), and making a few trials, we find that $\delta = -50^\circ$, and substituting this in either of the equations (A) or (B), we get $n = 5{\cdot}08$; and finally, by substituting these values of δ and n in either of the expressions for the constant quantity c, we get $c = 64674730000$, the 5·08 root of which is 134·27 very nearly; hence we have

$$F = \left\{ \frac{t + 50}{134{\cdot}27} \right\}^{5{\cdot}08} . \quad . \quad . \quad . \; (D).$$

Where the symbol F denotes generally the elastic force of the steam in inches of mercury, and t the corresponding temperature in degrees of Fahrenheit's thermometer. The logarithm of the denominator of the fraction is 2·1279717, which may be used as a constant in calculating the elastic force corresponding to any given temperature. We have thus discovered a rule of a very simple form, by which the results of Mr. Southern's experiments are represented with considerable accuracy; the rule errs in defect; but this might have been remedied by assuming two points near one extremity of the range of experiment, and two points near the other extremity; and by substituting the observed numbers in equation (C), different constants and a more correct exponent would accordingly have been obtained. Mr. Southern has, by pursuing a method somewhat analogous to that which is here described, found his experiments to be very nearly represented by

$$F = \left\{ \frac{t + 51{\cdot}3}{135{\cdot}767} \right\}^{5{\cdot}13}$$

But even here the formula errs in defect, for he has found it necessary to correct it by adding the arbitrary decimal 0·1; and thus modified, it becomes

$$F = \left\{ \frac{t + 51{\cdot}3}{135{\cdot}767} \right\}^{5{\cdot}13} + 0{\cdot}1 \quad . \quad . \quad . \quad . \; (E).$$

Our own formula may also be corrected by the application of some arbitrary constant of greater magnitude; but as our motive for tracing the steps of investigation in the foregoing case was to exemplify the method of determining the law of elasticity, our end is answered; for we consider it a very unsatisfactory thing merely to be put in possession of a formula purporting to be applicable to some particular purpose, without at the same time being put in possession of the method by which that formula was obtained, and the principles on which it rests. Having thus exhibited the principles and the method of reduction, the reader will have greater confidence as regards the consistency of the processes that he may be called upon to perform. The operation implied by equation (E) may be expressed in words as follows: —

RULE. *To the given temperature in degrees of Fahrenheit's thermometer add* 51·3 *degrees and divide the sum by* 135·767; *to the* 5·13 *power of the quotient add the constant fraction* $\frac{1}{10}$, *and the sum will be the elastic force in inches of mercury.*

The process here described is that which is performed by the rules of common arithmetic; but since the index is affected by a fraction, it is difficult to perform in that way: we must therefore have recourse to logarithms as the only means of avoiding the difficulty. The rule adapted to these numbers is as follows:—

RULE FOR LOGARITHMS. *To the given temperature in degrees of Fahrenheit's thermometer add* 51·3 *degrees; then, from the logarithm of the sum subtract* 2·1327940 *or the logarithm of* 135·767, *the denominator of the fraction; multiply the remainder by the index* 5·13, *and to the natural number answering to the sum add the constant fraction* $\frac{1}{10}$; *the sum will be the elastic force in inches of mercury.*

Example. If the temperature of steam be 250·3 degrees as indicated by Fahrenheit's thermometer, what is the corresponding elastic force in inches of mercury?

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[*] The modulus of elasticity of any substance is the measure of its elastic force; that of water at 60° of temperature is 22,100 atmospheres.

By the rule it is 250·3 + 51·3 = 301·6 log. 2·4794313
constant den. = 135·767 log. 2·1327940 subtract

remainder = 0·3466373
31·5 inverted

17331865
346637
103991

natural number 60·013 log. 1·7782493

If this be increased by $\frac{1}{10}$, we get 60·113 inches of mercury for the elastic force of steam at 250·3 degrees of Fahrenheit. Our own formula gives 59·6 inches, being one of the points employed in its derivation; we however by no means advise the application of this formula, we only state the circumstance as a proof of the soundness of the principle on which it is founded; and if we had adopted the same points in the range of experiment that Mr. Southern employed, it is more than probable that we should have obtained the same result, which would have been a convincing proof that he pursued a method analogous to our own, a circumstance that is immediately inferred from the form of the equation itself.

By simply reversing the process or transposing equation (E), the temperature corresponding to any given elastic force can easily be found; the transformed expression is as follows, viz.,

$$t = 135{\cdot}767\,(F - 0{\cdot}1)^{\frac{1}{5{\cdot}13}} - 51{\cdot}3 \quad . \; . \; . \; . \; (F).$$

Since, in consequence of the complicated index, the process of calculation cannot easily be performed by common arithmetic, it is needless to give a rule for reducing the equation in that way; we shall therefore at once give the rule for performing the process by logarithms.

RULE. *From the given elastic force in inches of mercury subtract the constant fraction* 0·1; *divide the logarithm of the remainder by* 5·13, *and to the quotient add the logarithm* 2·1327940; *find the natural number answering to the sum of the logarithms, and from the number thus found subtract the constant* 51.3, *and the remainder will be the temperature sought.*

Example. Supposing the elastic force of steam or the vapour of water to be equivalent to the weight of a vertical column of mercury, the height of which is 238·4 inches; what is the corresponding temperature in degrees of Fahrenheit's thermometer?

Here, by proceeding as directed in the rule, we have 238·4—0·1 = 238·3, and dividing the logarithm of this remainder by the constant exponent 5·13, we get

log. 238·3 ÷ 5·13 = 2·3771240 ÷ 5·13 = 0·4633770
constant coefficient = 135·767 - - log. 2·1327940 add

natural number = 394·61 - - - log. 2·5961710 sum
constant temperature = 51·3 subtract

required temperature = 343·31 degrees of Fahrenheit's thermometer.

The temperature by observation is 343·6 degrees, giving a difference of only 0·29 of a degree in defect, being as small an error as can well be expected when a computed result is compared with another deduced from experiment. These two examples, and the rules by which the solutions are effected, will suffice to show the application of Mr. Southern's principles to the determination of the elastic force of steam when the temperature is given, and also the temperature when the elastic force is given. For low temperature or low pressure steam, that is, steam not exceeding the simple pressure of the atmosphere, this formula as modified by Pambour agrees very nearly with the results of experiment, and when transformed into the measures generally used in practical inquiries, it becomes

$$p = 0{\cdot}04948 + \left(\frac{t + 51{\cdot}3}{155{\cdot}7256}\right)^{5{\cdot}13} . \; . \; . \; . \; (G).$$

In which equation the symbol p denotes the pressure in pounds avoirdupois per square inch, and t the temperature in degrees of Fahrenheit's thermometer. When this expression is reduced in reference to temperature, it is

$$t = 155{\cdot}7256(p - 0{\cdot}04948)^{\frac{1}{5{\cdot}13}} - 51{\cdot}3 \quad . \; . \; . \; . \quad (H).$$

We have dwelt thus particularly on Mr. Southern's formula, because it has long been considered by men of high authority as giving more correct results than can be obtained from the rules deduced by other experimentalists; indeed, had it been applicable with equal correctness to all temperatures within the range of practice, nothing more was wanting to enable the practical calculator to determine the several particulars connected with the application of steam as regards its pressure and temperature; but finding it to deviate considerably from the truth in high ranges, men of science became desirous of possessing a rule, by which the results of experiment should be more nearly represented, and accordingly we find that some of the most eminent chemical philosophers have had their attention directed to the subject, and their joint researches have supplied us with numerous formulæ for representing the law which connects the temperature of steam with its elastic force. The formula of Tredgold is well known; it is also founded on the experiments of Mr. Southern, and represents his results with great accuracy as far as they extend; it constitutes one of the simplest and most elegant expressions for representing the law of elasticity that has yet been found, and this it owes to the circumstance of involving no fractional numbers; but this very circumstance has caused it to be objected to by suggesting the idea that the constants are merely assumed, and not deduced by a legitimate process from the experimental data. The equation, in its original form, is

$$177f^{\frac{1}{6}} = t + 100 \, . \; . \; . \; . \quad (I):$$

where f denotes the elastic force of the steam in inches of mercury, and t the temperature in degrees of Fahrenheit's thermometer. The same formula, as modified and corrected by M. Millet, becomes

$$179{\cdot}0773f^{\frac{1}{6}} = t + 103 \; . \; . \; . \; . \quad (K).$$

This expression is something more complex than the one it is intended to supersede: but on trial we do not find it to produce more correct results; our readers however can employ the one or the other as they feel inclined.

Dr. Thomas Young constructed a formula which was adapted empirically to the experiments of Dr. Dalton: it assumed a form sufficiently simple and elegant, but involved a very high exponent; it is thus expressed—

$$f = (1 + 0{\cdot}0029t)^7 \quad . \; . \; . \; . \quad (L):$$

where the symbol f denotes the elastic force of steam expressed in atmospheres of 30 inches of mercury, and t the temperature in degrees estimated above 212 of Fahrenheit. This formula is not applicable in practice, especially in high temperatures, as it deviates very widely and rapidly from the results of observation: it is chiefly remarkable as being made the basis of a numerous class of theorems somewhat varied, but of a more correct and satisfactory character. Mr. Creighton applied a similar expression to Dr. Ure's experiments; but in order to represent them even approximately, he found it necessary to change the constant exponent from 7 to 6, making at the same time a correspondent alteration on the other constants which the expression contains. The Commission of the French Academy represented their experiments by means of a formula constructed on the same principles: it is thus expressed—

$$f = (1 + 0{\cdot}7153t)^5 \quad . \; . \; . \; . \quad (M):$$

where f denotes the elastic force of the steam expressed in atmospheres of 0·76 metres or 29·922 inches of mercury, and t the temperature estimated above 100 degrees of the centigrade thermometer; but when the same formula is so transformed as to be expressed in the usual terms adopted in practice, it is

$$p = (0{\cdot}2679 + 0{\cdot}0067585\,t)^5 \, . \; . \; . \; . \quad (N):$$

where p is the pressure in pounds per square inch, and t the temperature in degrees of Fahrenheit's scale, estimated above 212 or simple atmospheric pressure.

The committee of the Franklin Institute adopted the exponent 6, and changed Dr. Young's constants 0·0029 into 0·00333; thus modified, they represented their experiments in the usual terms by the equation

$$p = (0{\cdot}460467 + 0{\cdot}00521478\,t)^6 . \; . \; . \; . \quad (O).$$

By combining Dr. Dalton's experiments with the mean between those of the French Academy and the Franklin Institute, we obtain the following equations, the one being applicable for temperatures below 212 degrees, and the other for temperatures above that point as far as 50 atmospheres. Thus, for low pressure steam, that is, for steam of less temperature than 212, it is

$$f = \left(\frac{t + 175}{387}\right)^{7{\cdot}71307} . \; . \; . \; . \, (P).$$

and for steam above the temperature of 212, it is

$$f = \left(\frac{t + 121}{333}\right)^{6{\cdot}48} . \; . \; . \; . \, (Q).$$

In consequence therefore of the high and imposing authority from which these formulæ are deduced, we shall adopt them in all our subsequent calculations relative to the steam engine; and in order to render their application easy and familiar, we shall translate them into rules in words at length, and illustrate them by the resolution of appropriate numerical examples; and for the sake of a systematic arrangement, we think proper to branch the subject into a series of problems, as follows:—

The temperature of steam being given in degrees of Fahrenheit's thermometer, to find the corresponding elastic force in inches of mercury.

The problem, as here propounded, is resolved by one or other of the two last equations, and the process indicated by the arrangement is thus expressed:—

RULE. To the given temperature expressed in degrees of Fahrenheit's thermometer, add the constant temperature 175; find the logarithm answering to the sum, from which subtract the constant 2·587711; multiply the remainder by the index 7·71307, and the product will be the logarithm of the elastic force in atmospheres of 30 inches of mercury when the given temperature is less than 212 degrees. But when the temperature is greater than 212, increase it by 121; then, from the logarithm of the temperature thus increased, subtract the constant logarithm 2·522444, multiply the remainder by the exponent 6·42, and the product will be the logarithm of the elastic force in atmospheres of 30 inches of mercury; which being multiplied by 30 will give the force in inches, or if multiplied by 14·76 the result will be expressed in pounds avoirdupois per square inch.

Example. When steam is generated under a temperature of 187 degrees of Fahrenheit's thermometer, what is its corresponding elastic force in atmospheres of 30 inches of mercury?

In this example, the given temperature is less than 212 degrees: it will therefore be resolved by the first clause of the preceding rule, in which the additive constant is 175; hence we get

187 + 175 = 362 - - log. 2·558709

Constant divisor = 387 - - log. 2·587711 subtract

9·970998 × 7·71307 = 9·773393

And the corresponding natural number is 0·5934 atmospheres, or 17·802 inches of mercury, the elastic force required, or if expressed in pounds per square inch, it is 0·5934 × 14·76 = 8·76 lbs. very nearly. If the temperature be 250 degrees of Fahrenheit, the process is as follows:—

250 + 121 = 371 - - log. 2·569374

Constant divisor = 333 - - log. 2·522444 subtract

0·046930 × 6·42 = 0·301291

And the corresponding natural number is 2·0012 atmospheres, or 60·036 inches of mercury, and in pounds per square inch it is 2·0012 × 14·76 = 29·54 lbs. very nearly.

It is sometimes convenient to express the results in inches of mercury without a previous determination in atmospheres, and for this purpose the rule is simply as follows:—

Rule. Multiply the given temperature in degrees of Fahrenheit's thermometer by the constant coefficient 1·5542, and to the product add the constant number 271·985; then from the logarithm of the sum subtract the constant logarithm 2·587711, and multiply the remainder by the exponent 7·71307; the natural number answering to the product, considered as a logarithm, will give the elastic force in inches of mercury. This answers to the case when the temperature is less than 212 degrees; but when it is above that point proceed as follows:—

Multiply the given temperature in degrees of Fahrenheit's thermometer by the constant coefficient 1·69856, and to the product add the constant number 205·526; then from the logarithm of the sum subtract the constant logarithm 2·522444, and multiply the remainder by the exponent 6·42; the natural number answering to the product considered as a logarithm, will give the elastic force in inches of mercury. Take, for example, the temperatures as assumed above, and the process according to the rule is as follows:—

187 × 1·5542 = 290·6354

Constant = 271·985 add

Sum = 562·6204 - - log. 2·750216

Constant = 387 - - - log. 2·587711 subtract

0·162505 × 7·71307 = 1·253408

And the natural number answering to this logarithm is 17·923 inches of mercury. By the preceding calculation the result is 17·802; the slight difference arises from the introduction of the decimal constants, which in consequence of not terminating at the proper place are taken to the nearest unit in the last figure, but the process is equally true notwithstanding. For the higher temperature, we get

250 × 1·69856 = 424·640

Constant = 205·526 add

Sum = 630·166 - - log. 2·799456

Constant = 333 - - - log. 2·522444 subtract

0·277011 × 6·42 = 1·778410

And the natural number answering to this logarithm is 60·036 inches of mercury, agreeing exactly with the result obtained as above.

It is moreover sometimes convenient to express the force of the steam in pounds per square inch, without a previous determination in atmospheres or inches of mercury; and when the equations are modified for that purpose, they supply us with the following process: viz.

Multiply the given temperature by the constant coefficient 1·41666, and to the product add the constant number 247·9155; then, from the logarithm of the sum subtract the constant logarithm 2·587711, and multiply the remainder by the index 7·71307; the natural number answering to the product will give the pressure in pounds per square inch, when the temperature is less than 212 degrees; but for all greater temperatures the process is as follows:—

Multiply the given temperature by the constant coefficient 1·5209, and to the product add the constant number 184·0289; then, from the logarithm of the sum subtract the constant logarithm 2·522444, and multiply the remainder by the exponent 6·42; the natural or common number answering to the product, will express the force of the steam in pounds per square inch. If any of these results be multiplied by the decimal 0·7854, the product will be the corresponding pressure in pounds per circular inch. Taking therefore the temperatures previously employed, the operation is as follows:—

187 × 1·41666 = 264·9155

Constant = 247·9155 add

Sum = 512·8310 - - log. 2·709974

Constant = 387 - - - log. 2·587711 subtract

0·122263 × 7·71307 = 0·942656

And the number answering to this logarithm is 8·763 lbs. per square inch, and 8·763 × 0·7854 = 6·8824 lbs. per circular inch, the proportion in the two cases being as 1 to 0·7554. Again, for the higher temperature, it is

250 × 1·5209 = 380·2250

Constant = 184·0289 add

Sum = 564·2539 - - log. 2·751475

Constant = 333 - - - log. 2·522444 subtract

0·229031 × 6·42 = 1·470279

And the number answering to this logarithm is 29·568 lbs. per square inch, or 29568 × 0·7854 = 23·2226 lbs per circular inch.

We have now to reverse the process, and determine the temperature corresponding to any given power of the steam, and for this purpose we must so transpose the formulæ (P) and (Q), as to express the temperature in terms of the elastic force, combined with given constant numbers; but as it is probable that many of our readers would prefer to see the theorems from which the rules are deduced, we here subjoin them.

For the lower temperature, or that which does not exceed the temperature of boiling water, we get

$$t = 249 f^{\frac{1}{7{\cdot}71307}} - 175 \quad . \quad . \quad . \quad . \quad (R).$$

Where t denotes the temperature in degrees of Fahrenheit's thermometer, and f the elastic force in inches of mercury, less than 30 inches, or one atmosphere; but when the elastic force is greater than one atmosphere, the formula for the corresponding temperature is as follows:—

$$t = 196 f^{\frac{1}{6{\cdot}42}} - 121 \quad . \quad . \quad . \quad . \quad (S).$$

In the construction of these formulæ, we have, for the sake of simplicity, omitted the fractions that obtain in the coefficient of f; for since they are very small, the omission will not produce an error of any consequence; indeed no error will arise on this account, as we retain the correct logarithms, a circumstance that enables the computer to ascertain the true value of the coefficients whenever it is necessary so to do; but in all cases of actual practice, the results derived from the integral coefficients will be quite sufficient. The rule supplied by the equations (R) and (S) is thus expressed:—

When the elastic force is less than the pressure of the atmosphere, that is, less than 30 inches of the mercurial column,—

Rule. Divide the logarithm of the given elastic force in inches of mercury, by the constant index 7·71307, and to the quotient add the constant logarithm 2·396204; then from the common or natural number answering to the sum, subtract the constant temperature 175 degrees, and the remainder will be the temperature sought in degrees of Fahrenheit's thermometer. But when the elastic force exceeds 30 inches or one atmosphere, the following rule applies:—

Divide the logarithm of the given elastic force in inches of mercury by the constant index 6·42, and to the quotient add the constant logarithm 2·292363; then, from the natural number answering to the sum subtract the constant temperature 121 degrees, and the remainder will be the temperature sought. Similar rules might be constructed for determining the temperature, when the pressure in pounds per square inch is given; but since this is a less useful case of the problem we have thought proper to omit it. We therefore proceed to exemplify the above rules, and for this purpose we shall suppose the pressure in the two cases to be equivalent to the weight of 19 and 60 inches of mercury respectively. The operation will therefore be as follows:—

Log. 19 ÷ 7·71307 = 1·278754 ÷ 7·71307 = 0·165791

Constant coefficient = 249 - - log. 2·396204 add

Natural number = 364·75 - - log. 2·561995

Constant temperature = 175 subtract

Required temperature = 189·75 degrees of Fahrenheit's scale.

For the higher elastic force, the operation is as follows:—

Log. 60 ÷ 6·42 = 1·778151 ÷ 6·42 = 0·276969

Constant coefficient = 196 - log. 2·292363, add

Natural number = 370·97 - log. 2·569332

Constant temperature = 121 subtract

Required temperature = 249·97 degrees of Fahrenheit's scale.

All the preceding results, as computed by our rules, agree as nearly with observation as can be desired; but they have all been obtained on the supposition that the steam is in contact with the liquid from which it is generated; and in this case it is evident that the steam must always attain an elastic force corresponding to the temperature; and in accordance to any increase of pressure, supposing the temperature to remain the same, a quantity of it corresponding to the degree of compression must simply be condensed into water, and in consequence will leave the diminished space occupied by steam of the original degree of tension; or otherwise to express it, if the temperature and pressure invariably correspond with each other, it is impossible to increase the density and elasticity of the steam except by increasing the temperature at the same time; and contrariwise, the temperature cannot be increased without at the same time increasing the elasticity and density. This being admitted, it is obvious that under these circumstances the steam must always maintain its maximum of pressure and density: but if it be separated from the liquid that produces it, and if its temperature in this case be increased, it will be found not to possess a higher degree of elasticity than a volume of atmospheric air similarly confined, and heated to the same temperature. Under this new condition, the state of maximum density and elasticity ceases; for it is obvious that since no water is present, there cannot be any more steam generated by an increase of temperature; and consequently the force of the steam is only that which confines it to its original bulk, and is measured by the effort which it exerts to expand itself. Our next object therefore is to inquire what is the law of elasticity of steam under the conditions that we have here specified.

The specific gravity of steam, its density, and the volume which it occupies at different temperatures, have been determined by experiment with very great precision; and it has also been ascertained that the expansion of vapour by means of heat is regulated by the same laws as the expansion of the other gases, viz., that all gases expand from unity to 1·375 in bulk by 180 degrees of temperature; and again, that steam obeys the law discovered by Boyle and Mariotte, contracting in volume in proportion to the degree of pressure which it sustains. We have therefore to inquire what space a given quantity of water converted into steam will occupy at a given pressure; and from thence we can ascertain the specific gravity, density, and volume at all other pressures.

When a gas or vapour is submitted to a constant pressure, the quantity which it expands by a given rise of temperature is calculated by the following theorem,

$$v' = v\left(\frac{t'+459}{t+459}\right) \cdot \cdot \cdot \cdot \cdot \cdot \text{(T)}$$

where t and t' are the temperatures and v, v' the corresponding volumes before and after expansion; hence this rule.

Rule. *To each of the temperatures before and after expansion, add the constant experimental number* 459; *divide the greater sum by the lesser, and multiply the quotient by the volume at the lower temperature, and the product will give the expanded volume.*

Example. If the volume of steam at the temperature of 212 degrees of Fahrenheit be 1711 times the bulk of the water that produces it; what will be its volume at the temperature of 250·3 degrees, supposing the pressure to be the same in both cases?

Here, by the rule, we have $212+459=671$, and $250{\cdot}3+459=709{\cdot}3$; consequently, by dividing the greater by the lesser, and multiplying by the given volume, we get $\frac{709{\cdot}3}{671}\times 1711 = 1808{\cdot}66$ for the volume at the temperature of 250·3 degrees.

Again, if the elastic force at the lower temperature and the corresponding volume be given, the elastic force at the higher temperature can readily be found; for it is simply as the volume the vapour occupies at the lower temperature is to the volume at the higher temperature, or what it would become by expansion, so is the elastic force given to that required.

If the volume which steam occupies under any given pressure and temperature be given, the volume which it will occupy under any proposed pressure can readily be found by reversing the preceding process; or by referring to chemical tables containing the specific gravity of the gases compared with air as unity at the same pressure and temperature. Now air at the mean state of the atmosphere has a specific gravity of $1\frac{2}{9}$ as compared with water at 1000; and the bulks are inversely as the specific gravities, according to the general laws of the properties of matter previously announced in the pages of this work; hence it follows that air is 818 times the bulk of an equal weight of water, for $1000 \div 1\frac{2}{9} = 818{\cdot}18$. But by the experiments of Dr. Dalton, it has been found that steam of the same pressure and temperature has a specific gravity of ·625 compared with air as unity; consequently, we have only to divide the number 818·18 by ·625, and the quotient will give the proportion of volume of the vapour to one of the liquid from which it is generated; thus we get $818{\cdot}18 \div {\cdot}625 = 1309$; that is, the volume of steam at 60 degrees of Fahrenheit, its force being 30 inches of mercury, is 1309 times the volume of an equal weight of water; hence it follows, from equation (T), that when the temperature increases to t', the volume becomes

$$v' = 1309 \times \left(\frac{459+t'}{459+60}\right) = 2{\cdot}524(459+t');$$

and from this expression, the volume corresponding to any specified elastic force f, and temperature t', may easily be found; for it is inversely as the compressing force; that is,

$$f : 30 :: 2{\cdot}525\,(459+t') : v';$$

consequently, by working out the analogy, we get

$$v' = \frac{75{\cdot}67(459+t')}{f}. \cdot \cdot \cdot \cdot \text{(U)}$$

By this theorem is found the volume of steam as compared with that of the water producing it, when under a pressure corresponding to the temperature. The rule in words is as follows:

Rule. *Calculate the elastic force in inches of mercury by the rule already given for that purpose, and reserve it for a divisor. To the given temperature add the constant number* 459, *and multiply the sum by* 75·67; *then divide the product by the reserved divisor, and the quotient will give the volume sought.*

Example. When the temperature of steam is 250·3 degrees of Fahrenheit's thermometer, what is the volume, compared with that of water?

The temperature being greater than 212 degrees, the force is calculated by the rule to equation (Q), and the process is as follows:

250·3 + 121 = 371·3 log. 2·5697249
Constant divisor = 333 log. 2·5224442, subtract

0·0472807 × 6·42 = 0·3035421
Atmosphere = 30 inches of mercury log. 1·4771213, add

$$\begin{array}{lll} \text{Elastic force} = 60{\cdot}348 & & \text{log. } 1{\cdot}7806634 \\ \text{Again it is,} & & \\ 459 + 250{\cdot}3 = 709{\cdot}3 \text{ log. } 2{\cdot}8508300 & \left.\right\} \text{add} & \\ \text{Constant coefficient} = 75{\cdot}67 \text{ log. } 1{\cdot}8789237 & & 4{\cdot}7297537 \end{array} \left.\vphantom{\begin{array}{l}a\\a\\a\\a\end{array}}\right\} \text{subtract.}$$

Volume = 889·39 times that of water, log. 2·9490903 remainder.

Thus have we given the method of calculating the elastic force of steam when the temperature is given either in atmospheres or inches of mercury, and also in pounds or the square or circular inch: we have also reversed the process, and determined the temperature corresponding to any given elastic force. We have, moreover, shown how to find the volume corresponding to different temperatures, when the pressure is constant; and finally, we have calculated the volume, when under a pressure due to the elastic force. These are the chief subjects of calculation as regards the properties of steam; and we earnestly advise our readers to render themselves familiar with the several operations. The calculations as regards the motion of steam in the parts of an engine to produce power, will be considered in another part of the present treatise.

The equation (U), we may add, can be exhibited in a different form involving only the temperature and known quantities; for since the expressions (P) and (Q) represent the elastic force in terms of the temperature, according as it is under or above 212 degrees of Fahrenheit. we have only to substitute those values of the elastic force when reduced to inches of mercury, instead of the symbol f in equation (U), and we obtain, when the temperature is less than 212 degrees,

$$\text{Volume} = 75{\cdot}67(\text{temp.}+459) \div (0{\cdot}004016 \times \text{temp.} + 0{\cdot}702807)^{7{\cdot}71307} \quad \text{(V)}$$

and when the temperature exceeds 212 degrees, the expression becomes

$$\text{Volume} = 75{\cdot}67(\text{temp.}+459) \div 00{\cdot}005101 \times \text{temp.} + 0{\cdot}617195)^{6{\cdot}42} \quad \text{(W)}$$

These expressions are simple in their form, and easily reduced; but, in pursuance of the plan we have adopted, it becomes necessary to express the manner of their reduction in words at length, as follows:

Rule. When the given temperature is under 212 degrees, multiply the temperature in degrees of Fahrenheit's thermometer by the constant fraction 0·004016, and to the product add the constant increment 0·702807; multiply the logarithm of the sum by the index 7·71307, and find the natural or common number answering to the product, which reserve for a divisor. To the temperature add the constant number 459, and multiply the sum by the coefficient 75·67 for a dividend; divide the latter result by the former, and the quotient will express the volume of steam when that of water is unity.

Again, when the given temperature is greater than 212 degrees, multiply it by the fraction 0·005101, and to the product add the constant increment 0·617195; multiply the logarithm of the sum by the index 6·42, and reserve the natural number answering to the product for a divisor; find the dividend as directed above, which, being divided by the divisor, will give the volume of steam when that of the water is unity.

Example. How many cubic feet of steam will be supplied by one cubic foot of water, under the respective temperatures of 187 and 293·4 degrees of Fahrenheit's thermometer?

Here, by the rule, we have

187 × 0·004016 = 0·750992
Constant increment = 0·702807

Sum = 1·453799 log. 0·1625043 × 7·71307 = 1.2534069

and the number answering to this logarithm is 17·92284, the divisor. But 187 + 459 = 646, and 646 × 75·67 = 48882·82, the dividend; hence, by division, we get 48882·82 ÷ 17·92284 = 2727·4 cubic feet of steam from one cubic foot of water.

Again, for the higher temperature, it is

$$293{\cdot}4 \times 0{\cdot}005101 = 1{\cdot}496633$$
$$\text{Constant increment} = 0{\cdot}617195$$
$$\text{Sum } 2{\cdot}113828 \ - \ \text{log. } 0{\cdot}3250696 \times 6{\cdot}42 = 2{\cdot}0869468;$$

and the number answering to this logarithm is 122·165, the divisor. But 293·4 + 459 = 752·4, and 752·4 × 75·67 = 56934·108, the dividend; therefore, by division, we get 56934·108 ÷ 122·165 = 466·04 cubic feet of steam from one cubic foot of water.

The preceding is a very simple process for calculating the volume which the steam of a cubic foot of water will occupy when under a pressure due to a given temperature and elastic force; and since a knowledge of this particular is of the utmost importance in calculations connected with the steam engine, it is presumed that our readers will find it to their advantage to render themselves familiar with the method of obtaining it. The above example includes both cases of the problem, a circumstance which gives to the operation, considered as a whole, a somewhat formidable appearance: but it would be difficult to conceive a case in actual practice where the application of both the formulæ will be required at one and the same time; the entire process must therefore be considered as embracing only one of the cases above exemplified; and consequently it can be performed with the greatest ease and facility by every person who is acquainted with the use of logarithms; and those unacquainted with the application of logarithms ought to make themselves masters of that very simple mode of computation.

Another thing which it is necessary sometimes to discover in reasoning on the properties of steam as referred to its action in a steam engine, is the weight of a cubic foot, or any other quantity of it, expressed in grains, corresponding to a given temperature and pressure. Now, it has been ascertained by experiment, that when the temperature of steam is 60 degrees of Fahrenheit, and the pressure equal to 30 inches of mercury, the weight of a cubic foot in grains is 329·4; but the weight is directly proportional to the elastic force, for the elastic force is proportional to the density: consequently, if f denote any other elastic force, and w the weight in grains corresponding thereto, then we have

$$30 : f :: 329{\cdot}4 : w = 10{\cdot}98 f,$$

the weight of a cubic foot of vapour at the force f, and temperature 60 degrees of Fahrenheit. Let t denote the temperature at the force f; then by equation (T), we have $v = \frac{459 + t}{459 + 60} = \frac{459 + t}{519}$, the volume at the temperature t, supposing the volume at 60 degrees to be unity; that is, one cubic foot. Now, since the densities are inversely proportional to the spaces which the vapour occupies, we have $\frac{(459 + t)}{519} : 1 :: w : w' = \frac{519 w}{459 + t}$; but by the preceding analogy, the value of w is $10{\cdot}98 f$; therefore, by substitution, we get

$$w' = \frac{5698{\cdot}62 f}{459 + t} \quad . \ . \ . \ . \quad (X).$$

This equation expresses the weight in grains of a cubic foot of steam at the temperature t and force f; and if we substitute the value of f, from equations (P) and (Q), reduced to inches of mercury, and modified for the two cases of temperature below and above 212 degrees of Fahrenheit, we shall obtain, in the first case,

$$w' = (0{\cdot}012324 \times \text{temp.} + 2{\cdot}155611)^{7{\cdot}71307} \div (\text{temp.} + 459). \ . \ . \ . \ (Y)$$

and for the second case, where the temperature exceeds 212, it is

$$w' = (0{\cdot}01962 \times \text{temp.} + 2{\cdot}37374)^{6{\cdot}42} \div (\text{temp.} + 459) \ . \ . \ . \ (Z)$$

These two equations, like those marked (V) and (W), are sufficiently simple in their form, and offer but little difficulty in their application. The rule for their reduction, when expressed in words at length, is as follows:

Rule. When the temperature is less than 212 degrees, multiply the given temperature, in degrees of Fahrenheit's thermometer, by the fraction 0·012324, and to the product add the constant increment 2·155611; then multiply the logarithm of the sum by the index 7·71307, and from the product subtract the logarithm of the temperature, increased by 459; the natural number answering to the remainder will be the weight of a cubic foot in grains.

Again, when the temperature exceeds 212, multiply it by the fraction 0·01962, and to the product add the constant increment 2·37374; then multiply the logarithm of the sum by the index 6·42, and from the product subtract the logarithm of the temperature increased by 459; the natural number answering to the remainder will be the weight of a cubic foot in grains.

Example. Supposing the temperatures to be as in the preceding exemple, what will be the weight of a cubic foot in grains for the two cases?

Here, by the rule, we have

$$187 \times 0{\cdot}012324 = 2{\cdot}304588$$
$$\text{Constant increment} = 2{\cdot}155611$$
$$\text{Sum} = 4{\cdot}460199 \ - \ \text{log. } 0{\cdot}6493542 \times 7{\cdot}71307 = 5{\cdot}0085143$$
$$187 + 459 = 646 \ - \ - \ - \ - \ - \ \text{log. } 2{\cdot}8102325, \text{ subtract}$$
$$\text{Natural number} = 157{\cdot}863 \text{ grains per cubic foot} \ - \ \text{log. } 2{\cdot}1982818$$

For the higher temperature, it is

$$293{\cdot}4 \times 0{\cdot}01962 = 5{\cdot}756508$$
$$\text{Constant increment} = 2{\cdot}373740$$
$$\text{Sum} = 8{\cdot}130248 \ - \ \text{log. } 0{\cdot}9101038 \times 6{\cdot}42 = 5{\cdot}8428664$$
$$293{\cdot}4 + 459 = 752{\cdot}4 \ - \ - \ - \ - \ \text{log. } 2{\cdot}8764488, \text{ subtract}$$
$$\text{Natural number} = 925{\cdot}59 \text{ grains per cubic foot} \ - \ \text{log. } 2{\cdot}9664176.$$

Here again the operation resolves both cases of the problem; but in practice only one of them can be required.

THE MOTION OF ELASTIC FLUIDS.

The next subject that claims our attention is the velocity with which elastic fluids or vapours move in pipes or confined passages. It is a well-known fact in the doctrine of pneumatics, that the motion of free elastic fluids depends upon the temperature and pressure of the atmosphere; and, consequently, when an elastic fluid is confined in a close vessel, it must be similarly circumstanced with regard to temperature and pressure as it would be in an atmosphere competent to exert the same pressure upon it. The simplest and most convenient way of estimating the motion of an elastic fluid is to assign the height of a column of uniform density, capable of producing the same pressure as that which the fluid sustains in its state of confinement; for under the pressure of such a column, the velocity into a perfect vacuum will be the same as that acquired by a heavy body in falling through the height of the homogeneous column, a proper allowance being made for the contraction at the aperture or orifice through which the fluid flows.

When a passage is opened between two vessels containing fluids of different densities, the fluid of greatest density rushes out of the vessel that contains it, into the one containing the rarer fluid, and the velocity of influx at the first instant of the motion is equal to that which a heavy body acquires in falling through a certain height, and that height is equal to the difference of two uniform columns of the fluid of greatest density, competent to produce the pressures under which the fluids are originally confined; and the velocity of motion at any other instant is proportional to the square root of the difference between the heights of the uniform columns producing the pressures at that instant. Hence we infer that the velocity of motion continually decreases,—the density of the fluids in the two vessels approaching nearer and nearer to an equality, and after a certain time an equilibrium obtains, and the velocity of motion ceases.

It is abundantly confirmed by observation and experiment, that oblique action produces very nearly the same effect in the motion of elastic fluids through apertures as it does in the case of water; and it has moreover been ascertained that eddies take place under similar circumstances, and these eddies must of course have a tendency to retard the motion: it therefore becomes necessary, in all the calculations of practice, to make some allowance for the retardation that takes place in passing the orifice; and this end is most conveniently answered by modifying the constant coefficient according to the nature of the aperture through which the motion is made. Numerous experiments have been made to ascertain the effect of contraction in orifices of different forms and under different conditions, and amongst those which have proved the most successful in this respect, we may mention the experiments of Du Buat and Eytelwein, the latter of whom has supplied us with a series of coefficients, which, although not exclusively applicable to the case of the steam engine, yet, on account of their extensive utility, we take the liberty to transcribe. They are as follow:—

1. For the velocity of motion that would result from the direct unretarded action of the column of the fluid that produces it, we have - - - -	$3V = \sqrt{579h}$
2. For an orifice or tube in the form of the contracted vein - - - - - - -	$10V = \sqrt{6084h}$
3. For wide openings having the sill on a level with the bottom of the reservoir - - - -	$10V = \sqrt{5929h}$
4. For sluices with walls in a line with the orifice -	
5. For bridges with pointed piers - - -	
6. For narrow openings having the sill on a level with the bottom of the reservoir - - -	$10V = \sqrt{4761h}$
7. For small openings in a sluice with side walls	
8. For abrupt projections - - - -	
9. For bridges with square piers - - -	
10. For openings in sluices without side walls - -	$10V = \sqrt{2601h}$
11. For openings or orifices in a thin plate - -	$V = \sqrt{25h}$
12. For a straight tube from 2 to 3 diameters in length projecting outwards - - - - -	$10V = \sqrt{4225}$
13. For a tube from 2 to 3 diameters in length projecting inwards - - - - - - -	$10V = \sqrt{2976{\cdot}25h}$

It is necessary to observe, that in all these equations V is the velocity of motion in feet per second, and h the height of the column producing it, estimated also in feet. Nos. 1, 2, 11, 12, and 13 are those which more particularly apply to the usual passages for the steam in a steam engine; but since all the others meet their application in the every-day practice of the civil engineer, we have thought it useful to supply them.

MOTION OF STEAM IN AN ENGINE.

We have already stated that the best method of estimating the motion of an elastic fluid, such as steam or the vapour of water, is to assign the height of a uniform column of that fluid capable of producing the pressure: the determination of this column is therefore the leading step of the inquiry; and since the elastic force of steam is usually reckoned in inches of mercury, 30 inches being equal to the pressure of the atmosphere, the subject presents but little difficulty; for we have already seen that the height of a column of water of the temperature of 60 degrees, balancing a column of 30 inches of mercury, is 34·023 feet; the corresponding column of steam must therefore be as its relative bulk and elastic force; hence we have $30 : 34{\cdot}023 :: fv : h = 1{\cdot}1341\,fv$, where f is the elastic force of the steam in inches of mercury, v the corresponding volume or bulk when that of water is unity, and h the height of a uniform column of the fluid capable of producing the pressure due to the elastic force; consequently, in the case of a direct unretarded action, the velocity into a perfect vacuum, according to No. 1 of the preceding class of formula, is $V = 8{\cdot}542\sqrt{fv}$; but for the best form of pipes, or a conical tube in form of the contracted vein, the velocity into a vacuum, according to No. 2, becomes $V = 8{\cdot}307\sqrt{fv}$; and for pipes of the usual construction, No. 12 gives $V = 6{\cdot}922\sqrt{fv}$; No. 13 gives $V = 5{\cdot}804\sqrt{fv}$; and in the case of a simple orifice in a thin plate, we get from No. 11 $V = 5{\cdot}322\sqrt{fv}$. The consideration of all these equations may occasionally be required, but our researches will at present be limited to that arising from No. 12, as being the best adapted for general practice; and for the purpose of shortening the investigation, we shall take no further notice of the case in which the temperature of the steam is below 212 degrees of Fahrenheit; for the expression which indicates the velocity into a vacuum being independent of the elastic force, a separate consideration for the two cases is here unnecessary.

It has been shown in the equation marked (U), that the volume of steam which is generated from an unit of water, is $v = \frac{75{\cdot}67\,(\text{temp.} + 459)}{f}$; let this value of v be substituted for it in the equation $V = 6{\cdot}922\sqrt{fv}$, and we obtain for the velocity into a vacuum for the usual form of steam passages, as follows, viz.,

$$V = 60{\cdot}2143\sqrt{(\text{temp.} + 459)}$$

This is a very neat and simple expression, and the object determined by it is a very important one: it therefore merits the reader's utmost attention, especially if he is desirous of becoming familiar with the calculations in reference to the motion of steam. The rule which the equation supplies, when expressed in words at length, is as follows:—

RULE. *To the temperature of the steam, in degrees of Farenheit's thermometer, add the constant number or increment* 459, *and multiply the square root of the sum by* 60·2143; *the product will be the velocity with which the steam rushes into a vacuum in feet per second.*

Example. With what velocity will steam of 293·4 degrees of Fahrenheit's thermometer rush into a vacuum when under a pressure due to the elastic force corresponding to the given temperature.

By the rule it is 293·4 + 459 = 752.4	-	½ log. 1·4382244	
Constant coefficient = 60·2143	-	log. 1·7797018	add
Velocity into a vacuum in feet per second = 1651·68		log. 3·2179262	

This is the velocity into a perfect vacuum, when the motion is made through a straight pipe of uniform diameter; but when the pipe is alternately enlarged and contracted, the velocity must necessarily be reduced in proportion to the nature of the contraction; and it is further manifest, that every bend and angle in a pipe will be attended with a correspondent diminution in the velocity of motion: it therefore behoves us, in the actual construction of steam passages, to avoid these causes of loss as much as possible; and where they cannot be avoided altogether, such forms should be adopted as will produce the smallest possible retarding effect. In cases where the forms are limited by the situation and conditions of construction, such corrections should be applied as the circumstances of the case demand; and the amount of these corrections must be estimated according to the nature of the obstructions themselves. For each right-angled bend, the diminution of velocity is usually set down as being about one-tenth of its unobstructed value; but whether this conclusion be correct or not, it is at least certain that the obstruction in the case of a right-angled bend is much greater than in that of a gradually curved one. It is a very common thing, especially in steam vessels, for the main steam pipe to send off branches at right angles to each cylinder, and it is easy to see that a great diminution in the velocity of the steam must take place here. In the expansion valve chest a further obstruction must be met with, probably to the extent of reducing the velocity of the steam two-tenths of its whole amount.

These proportional corrections are not to be taken as the results of experiments that have been performed for the purpose of determining the effect of the above causes of retardation: we have no experiments of this sort on which reliance can be placed; and, in consequence, such elements can only be inferred from a comparison of the principles that regulate the motion of other fluids under similar circumstances: they will, however, greatly assist the engineer in arriving at an approximate estimate of the diminution that takes place in the velocity in passing any number of obstructions, when the precise nature of those obstructions can be ascertained. In the generality of practical cases, if the constant coefficient 60·2143 be reduced in the ratio of 650 to 450, the resulting constant 41·6868 may be employed without introducing an error of any consequence.

OF THE ASCENT OF SMOKE AND HEATED AIR IN CHIMNEYS.

The subject of chimney flues, with the ascent of smoke and heated air, is another case of the motion of elastic fluids, in which, by a change of temperature, an atmospheric column assumes a different density from another, where no such alteration of temperature occurs. The proper construction of chimneys is a matter of very great importance to the practical engineer, for in a close fireplace, designed for the generation of steam, there must be a considerable draught to accomplish the intended purpose, and this depends upon the three following particulars, viz.—

1. The height of the chimney from the throat to the top.
2. The area of the transverse section.
3. The temperature at which the smoke and heated air are allowed to enter it.

The formula for determining the power of the chimney may be investigated in the following manner.

Put h = the height in feet from the place where the flue enters to the top of the chimney,
b = the number of cubic feet of air of atmospheric density that the chimney must discharge per hour,
a = the area of the aperture in square inches through which b cubic feet of air must pass when expanded by a change of temperature,
v = the velocity of ascent in feet per second,
t' = the temperature of the external air, and
t = the temperature of the air to be discharged by the chimney.

Now the force producing the motion in this case is manifestly the difference between the weight of a column of the atmospheric air and another of the air discharged by the chimney; and when the temperature of the atmospheric air is at 52 degrees of Fahrenheit's thermometer, this difference will be indicated by the term $h\left(\frac{t'-t}{t'+459}\right)$; the velocity of ascent will therefore be $v = \sqrt{64\tfrac{1}{3}h\left\{\frac{t'-t}{t'+459}\right\}}$ feet per second, and the quantity of air discharged per second will therefore be, $a\sqrt{64\tfrac{1}{3}\left\{\frac{t'-t}{t'+459}\right\}}$, supposing that there is no contraction in the stream of air; but it is found by experiment, that in all cases the contraction that takes place diminishes the quantity discharged, by about three eighths of the whole; consequently, the quantity discharged per hour in cubic feet becomes

$$b = 125{\cdot}69\,a\sqrt{\frac{h(t'-t)}{t'+459}}.$$

This would be the quantity discharged, provided there were no increase of volume in consequence of the change of temperature; but air expands from b to $\frac{b(t'+549)}{t+459}$ for $t'-t$ degrees of temperature, as has been shown elsewhere; consequently, by comparison, we have

$$\frac{b\,(t'+459)}{t+459} = 125{\cdot}69\,a\sqrt{\frac{h\,(t'-t)}{t+459}}.$$

From this equation, therefore, any one of the quantities which it involves can be found, when the others are given: it however supposes that there is no other cause of diminution but the contraction at the aperture; but this can seldom if ever be the case; for eddies, loss of heat, obstructions, and change of direction in the chimney, will diminish the velocity, and consequently a larger area will be required to suffer the heated air to pass. A sufficient allowance for these causes of retardation will be made, if we change the coefficient 125·69 to 100; and in this case the equation for the area of section becomes

$$a = b\sqrt{(t'+459)^3} \div 100\,(t+459)\sqrt{h\,(t'-t)}.$$

And if we take the mean temperature of the air of the atmosphere at 52 degrees of Fahrenheit, and make an allowance of 16 degrees for the difference of density between atmospheric air and cool smoke, our equation will ultimately assume the form

$$a = b\sqrt{(t'+459)^3} \div 51100\sqrt{h(t'-t-16)}.$$

It has been found by experiment that 200 cubic feet of air of atmospheric density are required for the complete combustion of one pound of coal, and the consumption of ten pounds of coal per hour is usually reckoned equivalent to one horse power: it therefore appears that 2000 cubic feet of air per hour must pass through the fire for each horse power of the engine. This is a large allowance, but it is the safest plan to calculate in excess in the first instance; for the chimney may afterwards be convenient, even if considerably larger than is necessary. The rule for reducing the equation is as follows:—

Rule. *Multiply the number of horse power of the engine by the* $\frac{3}{2}$ *power of the temperature at which the air enters the chimney, increased by* 459; *then divide the product by* 25·55 *times the square root of the height of the chimney in feet, multiplied by the difference of temperature, less* 16 *degrees, and the quotient will be the area of the chimney in square inches.*

Example. Suppose the height of the chimney for a 40 horse engine to be 70 feet, what should be its area when the difference between the temperature at which the air enters the flue, and that of the atmosphere, is 250 degrees?

Here, by the rule, we have

250 + 52 = 302, the temperature at which the air enters the flue.
Constant increment = 459,

Sum = 761 - - - log. 2·8813847
3

2)8·6441541

4·3220770
Number of horse power = 40 - - - log. 1·6020600

5·9241370

250 − 16 = 234 - log. 2·3692159
height = 70 feet - log. 1·8450980

2)4·2143139

2·1071569
Constant = 25·55 - log. 1·4073909 } - 3·5145478

Hence the area of the chimney in square inches is 256·79, log. 2·4095892; and in this way may the area be calculated for any other case; but particular care must be taken to have the data accurately determined before the calculation is begun. In the above example the particulars are merely assumed; but even that is sufficient to show the process of calculation, which is more immediately the object of the present inquiry. It is right, however, to add, that recent experiments have greatly shaken the doctrine that it is beneficial to make chimneys small at the top, though such is the way in which they are, nevertheless, still constructed, and our rules must have reference to the present practice. It appears, however, that it would be the best way to make chimneys to expand as they ascend, after the manner of a trumpet, with its mouth turned downwards: but these experiments require farther confirmation.

The method of calculation adopted above is founded on the principle of correcting the temperature for the difference between the specific gravity of atmospheric air and that of coal smoke, the one being unity and the other 1·05; there is, however, another method, somewhat more elegant and legitimate, by employing the specific gravity of coal-smoke itself: the investigation is rather tedious and prolix, but the resulting formula is by no means difficult; and since both methods give the same result when properly calculated, we make no further apology for presenting our readers with another rule for obtaining the same object. The formula is as follows:—

$$a = \frac{b\,(t' + 459)}{2757{\cdot}5} \sqrt{\frac{1}{h\,(t' - 77{\cdot}55)}}$$

where a is the area of the transverse section of the chimney in square inches, b the quantity of atmospheric air required for combustion of the coal in cubic feet per hour, h the height of the atmosphere in feet, and t' the temperature at which the air enters the flue after passing through the fire. The rule for performing this process is thus expressed:—

Rule. *From the temperature at which the air enters the chimney, subtract the constant decrement* 77·55; *multiply the remainder by the height of the chimney in feet, divide unity by the product, and extract the square root of the quotient. To the temperature of the heated air, add the constant number* 459; *multiply the sum by the number of cubic feet required for combustion per hour, and divide the product by the number* 2757·5; *then multiply the quotient by the square root found as above, and the product will be the number of square inches in the transverse section of the chimney.*

Example. Suppose a mass of fuel in a state of combustion to require 5000 cubic feet of air per hour, what must be the size of the chimney when its height is 100 feet, the temperature at which the heated air enters the chimney being 200 degrees of Fahrenheit's thermometer?

By the rule we have 200 — 77·55 = 122·45 - log. 2·0879588
Height of the chimney = 100 - - log. 2·0000000

4·0879588

2)5·9120412

7·9560206

200 + 459 = 659 - log. 2·8188854
5000 - log. 3·6989700 } add 3·0773399
2757·5 ar. co. log. 6·5594845

1·0333605 10·798 inches.

This appears to be a very small flue for the quantity of air that passes through it per hour; but it must be observed that we have assumed a great height for the shaft, which has the effect of creating a very powerful draught, thereby drawing off the heated air with great rapidity.

The advantage of a high flue is so very great, that the reader may be desirous of knowing to what height a chimney of a given base may be carried with safety, in cases where it is inconvenient to secure it with lateral stays; and, as an approximate rule for this purpose is not difficult of investigation, we think proper to supply it here.

When the chimney is equally wide throughout its whole height, the formula is

$$s = h\sqrt{\frac{156}{12000 - \frac{1}{3}\,h\,w}};$$

but when the side of the base is double the size of the top, the equation becomes

$$s = h\sqrt{\frac{104}{12000 - 0{\cdot}42\,h\,w}};$$

where s is the side of the base in feet, h the height, and w the weight of one cubic foot of the material. When the chimney stalk is not square, but longer on the one side than the other, s must be the least dimension. The proportion of solid wall to a given base, as sanctioned by experience, is about two thirds of its area, consequently w ought to be two thirds of the weight of a cubic foot of brickwork. Now a cubic foot of dried brickwork is on an average 114 lbs; consequently $w = 76$ lbs; and if this be substituted in the foregoing equations, we get for a chimney of equal size throughout,

$$s = h\sqrt{\frac{156}{1200 - 25h}};$$

and when the chimney tapers to one half the size at top, it is

$$s - h\sqrt{\frac{104}{12000 - 32h}};$$

where it may be remarked that 12000 lbs. is the cohesive force of one square foot of mortar; and in the investigation of the formulæ we have assumed the greatest force of the wind on a square foot of surface at 52 lbs. These equations are too simple in their form to require elucidation from us; we therefore leave the reduction as an exercise to the reader, who it is presumed will find no difficulty in resolving the several cases that may arise in the course of his practice.

CHAPTER I.

PRINCIPLES TO BE OBSERVED IN THE CONSTRUCTION OF BOILERS.

HAVING now explained in a general way the scientific principles concerned in the use of steam as a motive power, we have next to exhibit the practical application of those principles; and we begin with the subject of boilers. And it may not be superfluous to repeat, that, however useful an acquaintance with scientific principles may be, it would be a most unsafe course to take them as a sufficient guide in the actual operations of engineering; for they have in almost every case to receive material modifications, before they can be considered representative of a judicious and successful practice. At best, scientific principles give only general conclusions, and afford an approximation to the position in which the truth lies; but practice reveals many conclusions which science could not anticipate, and which may modify or even reverse its decisions. Precepts, therefore, derived from theory alone, are but of little value until confirmed by the results of experience, as embodied in successful practice; and to this more important division of the subject we shall now direct our attention.

We have already given a theoretical rule for the dimensions of a land engine chimney. Boulton and Watt's practical rule for the dimensions of the chimney of a land engine is as follows:—multiply the number of pounds of coal consumed under the boiler per hour by 12, and divide the product by the square root of the height of the chimney in feet; the quotient is the area of the chimney in square inches in the smallest part. A factory chimney suitable for a 20 horse boiler is commonly made about 20 in. square inside, and 80 ft. high; and these dimensions are those which answer to a consumption of 15 lbs. of coal per horse power per hour, which is a very common consumption in factory engines. If 15 lbs. of coal be consumed per horse power per hour, the total consumption per hour in a 20 horse boiler, will be 300 lbs., and 300 multiplied by 12 = 3,600, and divided by 9 (the square root of the height) = 400, which is the area of the chimney in square inches. It will not answer well to increase the height of a chimney of this area to more than 40 or 50 yards, without also increasing the area, nor will it be of utility to increase the area much without also increasing the height. The quantity of coal consumed per hour in pounds, multiplied by 5, and divided by the square root of the height of the chimney, is the proper collective area of the openings between the bars of the grate for the admission of air to the fire. In steam vessels Boulton and Watt allow 8½ square inches of area of chimney per horse power, and in marine flue boilers they allow 18 square inches of sectional area of flue per horse power; but this proportion appears to be about one-third greater than what is allowed by many other makers, whose boilers, however, are scarcely so conspicuous for an abundant supply of steam. The sectional area of the flue in square inches is what is termed the *calorimeter* of the boiler, and the calorimeter divided by the length of the flue in feet is what is termed the *vent*. In marine flue boilers of good construction the vent varies between the limits of 21 and 25, according to the size of the boiler and other circumstances—the largest boilers having generally the largest vents; and the calorimeter divided by the vent will give the length of the flue in feet. The collective area for the escape of the smoke and flame over the furnace bridges in marine boilers is 19 square inches per horse power, according to Boulton and Watt's proportion. In waggon and tubular boilers very different proportions prevail, yet the proportions of every kind of boiler are determinable on the same general principle. In waggon boilers the proportion of the perimeter of the flue which is effective as heating surface, is to the total perimeter as 1 to 3, or, in some cases, as 1 to 2·5; and with any given area of flue, therefore, the length of the flue must be from 3 to 2·5 times greater than would be necessary if the total surface were effective. If then the vent be the calorimeter divided by the length, and the length be made 3 or 2·5 times greater, the vent must become 3 or 2·5 times less; and in waggon boilers accordingly the vent varies from 8 to 11 instead of from 21 to 25, as in the case of marine flue boilers. In Boulton and Watt's 45 horse waggon boiler, the area of flue is 18 square inches per horse power, but the area per horse power increases very rapidly as the size of the boiler becomes less, and amounts to about 80 square inches per horse power in a boiler of two horse power. Some such increase is obviously inevitable if a similar form of flue be retained in the larger and smaller powers, and at the same time the elongation of the flue in the same proportion as the increase of any other dimension is prevented; but in the smaller class of waggon boilers the consideration of facility of cleaning the flues is also operative in inducing a large proportion of sectional area. Boulton and Watt's 2 horse power waggon boiler has 30 square feet of surface, and the flue is 18 in. high above the level of the boiler bottom, by 9 in. wide; while their 12 horse waggon boiler has 118 square feet of heating surface, and the dimensions of the flue similarly measured are 36 in. by 13 in. The width of the smaller flue, if similarly proportioned to the larger one, would be 6½ in., instead of 9 in., and, by assuming this dimension, we should have the same proportion of sectional area per square foot of heating surface in both boilers. The length of flue in the 2 horse boiler is 19·5 ft., and in the 12 horse boiler 39 ft., so that the length and height of the flue are increased in the same proportion. The Nile steamer, with engines of 110 horse power, by Boulton and Watt, is supplied with steam by two boilers, which are, therefore, of 55 horse power each. The height of the flue winding within the boiler is 60 in., and its mean width 16½ in., making a sectional area or calorimeter of 990 square inches, or 18 square inches per horse power of the boiler. The length of the flue is 39 ft., making the vent 25, which is the vent proper for large boilers. In the Dee and Solway steamers, by Scott and Sinclair, the calorimeter is only 9·72 square inches per horse power; in the Eagle, by Caird, 11·9; in the Thames and Medway, by Maudslay, 11·34, and in a great number of other cases it does not rise above 12 square inches per horse power, but the engines of most of these vessels are intended to operate to a certain extent expansively, and the boilers are less powerful in evaporating efficacy on that account.

The calorimeter *of each boiler* of the Dee and Solway is 1,296 square inches; of the Eagle, 1,548 square inches; and of the Thames and Medway 1,134 square inches; and the length of flue is 57, 60, and 52 ft. in the boilers respectively, which makes the respective vents 22¼, 25, and 21 in. Taking then the boiler of the Eagle for comparison with the boiler of the Nile, as it has the same vent, it will be seen that the proportions of the two are almost identical, for 990 is to 1,548 as 39 is to 60, nearly; but Messrs. Boulton and Watt would not have set a boiler like that of the Eagle to do so much work. The evaporating power varies as the square root of the area of the flue, if the length of the flue remain the same; but it varies as the area simply, if the length of the flue be increased in the same proportion as its other dimensions. The evaporating power of a boiler is referrible to the amount of its heating surface, and the amount of heating surface in any flue or tube is proportional to the product of the length of the tube and the square root of its sectional area, multiplied by a certain quantity that is constant for each particular form. But in similar tubes the length is proportional to the square root of the sectional area; therefore, in similar tubes, the amount of heating surface is proportional to the sectional area. On this area also depends the quantity of hot air passing through the flue, supposing the intensity of the draught to remain unaffected, and the quantity of hot air or smoke passing through the flue should vary in the same ratio as the quantity of surface. A boiler therefore to exert four times the power should have four times the extent of heating surface, and four times the sectional area of flue for the transmission of the smoke; and if the same form of flue is to be retained, it should be of twice the diameter and twice the length; or twice the height and width, if rectangular, and twice the length. As then the diameter or square root of the area increases in the same ratio as the length, the square root of the area divided by the length ought to be a constant quantity in each type of boiler, in order that the same proportions of flue may be retained; and in waggon boilers without an internal flue, the height in inches of the flue encircling the boiler divided by the length of the flue in feet will be 1 very nearly. Instead of the square root of the area the effective perimeter, or outline of that part of the cross section of the flue which is effective in generating steam, may be taken; and the effective perimeter divided by the length ought to be a constant quantity in similar forms of flue and with the same velocity of draft, whatever the size of the flue may be. It is clear, that with any given area of flue, to increase the perimeter by adopting a different shape, is to diminish the length of the flue; and, if the extent of the perimeter be diminished, the length of the flue must at the same time be increased, else it will be impossible to obtain the necessary amount of heating surface. In Boulton and Watt's waggon boilers the sectional area of the flue in square inches, per square foot of heating surface, is 5·4 in the two horse boiler; in the three horse it is 4·74; in the four horse 4·35; six horse, 3·75; eight horse, 4·33; ten horse, 3·96; twelve horse, 3·63; eighteen horse, 3·17; thirty horse, 2·52, and in the forty-five horse boiler, 2·05 square inches. Taking the amount of heating surface in the 45 horse boiler at 9 square feet per horse power, we obtain 18 square inches of sectional area of flue per horse power, which is also Boulton and Watt's proportion of sectional area for marine boilers with internal flues.

If to increase the perimeter of a flue is virtually to diminish the length, it is clear a tubular boiler, where the perimeter is in effect greatly extended, ought to have but a short length of tube. The flue of the Nile, if reduced to the cylindrical form, would be 35¼ in. in diameter, to have the same area; but it would then require to be made 47¾ ft. long, to have the same amount of heating surface. Supposing that with these proportions the heat is sufficiently extracted from the smoke, then every tube of a tubular boiler in which the same draft existed, ought to have very nearly the same proportions, so that a tube 3 in. in diameter ought to be about 4 ft. long, supposing the conducting power of the metallic surface through which the heat is transmitted, to be in each case identical. But the metal of small tubes being thinner than that of flues must conduct better, and a tube 3 in. in diameter should therefore be less than 4 ft. long, provided the draft remains such as is due to an area of 18 square inches per horse power. If the thinness of the metal attainable by the tubular form be supposed to increase the efficacy of the heating surface in the same proportion as the increase of surface due to the rectangular form, the length of a tube 3 in. diameter ought to be 3 ft. 3 in.; and it would be of no service to extend its length beyond this point, supposing the flue boiler to be properly proportioned, as by the time the hot air had traversed a length of 3 ft. 3 in. of tube, the heat of the air would have been as thoroughly extracted as in ordinary boilers appears to be beneficial. The tubes of tubular boilers, however, are usually about 6 ft. 6 in, long; but to make this excess of length influential in generating steam, the draft has to be made nearly twice greater than in flue boilers having a sectional area of 18 square inches per horse power, or in other words, the sectional area of tubular boilers must not much exceed 9 square inches per horse power when the tubes are of the length stated. The smaller the tubes are, the shorter they should be made, or the less the sectional area ought to be; and with a sectional area of 10 square inches per horse power, there will be no advantage in making the length of the tube more than from 26 to 32 times its diameter, which will make the tubes from 6 ft. 6 in. to 8 ft. long, when the diameter is three inches, and give from 7·4 to 8 square feet of heating surface of tubes per horse power. If the sectional area per horse power be increased, the length of tube should be diminshed in the same proportion; for the velocity of the draft varies with the sectional area of tube per horse power, and on the velocity of draft the length of the tube ought to depend.

In locomotive boilers where the velocity of draft is very great, long tubes are employed; but it is preferable to have the tubes of moderate length, and a draft of moderate intensity, as in maintaining a fierce draft by any process, there is a considerable expenditure of power. If, however, with the view of making the draft very slow, a proportion of sectional area approaching that of flue boilers be provided, the result will not be satisfactory, as the smoke will all pass through a few of the tubes, leaving the rest inoperative; though this defect may be in a great measure corrected by partially closing up the ends of the tubes, or even by partially closing the damper. The length of tube multiplied by the diameter, and divided by the area, is a constant quantity both in flue and tubular boilers, or at least nearly so; and when any of the elements are given, the rest can easily be computed by the aid of this proportion. Bury's locomotive with 14 in. cylinders contains 92 tubes of 2⅛th in. external diameter, and 10 ft. 6 in. long, whereas Stephenson's locomotive with 15 in. cylinders, contains 150 tubes of 1⅝ths external diameter, and 13 ft. 6 in. long. In Stephenson's boiler, in order that the part of the tubes next the chimney may be of any avail for the generation of steam, the draft has to be very intense, which in its turn involves a considerable expenditure of power; and it is questionable whether the increased expenditure of power upon the blast, in Stephenson's long tubed locomotives, is compensated by the increased generation of steam consequent upon the extension of the heating surface. When the tubes are small in diameter they are apt to become partially choked with pieces of coke, but an internal diameter of 1⅝ths may be employed without inconvenience, if the draft be of medium intensity. The intensity of the draft may easily be diminished by partially closing the damper in the chimney, and it may be increased by contracting the orifice of the blast. In most locomotives the velocity of the draft is such that it would require very long tubes to extract the heat from the products of combustion, if the heat were transmitted through the metal of the tubes with only the same facility as through the iron of ordinary flue boilers, and if it were required at the same time that the heat should be as thoroughly extracted. The Nile steamer, with engines of 110 nominal horses power each, and with two boilers having two independent flues in each, of such dimensions as to make each flue equivalent to 55 nominal horses power, works at 62 per cent. above the nominal power, so that the actual evaporative efficacy of each flue would be equivalent to 89 actual horses power, supposing the engines to operate without expansion; but as the mean pressure in the cylinder is somewhat less than the initial pressure, the evaporative efficacy of each flue may be reckoned equivalent to 80 actual horses power. With this evaporative power there is a calorimeter of 990 square inches, or 12·3 square inches per actual horse power, whereas in Stephenson's locomotive with 150 tubes, if the evaporative power be taken at 200 cubic feet of water in the hour, which makes the engine equal to 200 actual horses power, and the internal diameter of the tubes be taken at thirteen-eighths of an inch, the calorimeter per actual horse power will only be 1·1136 square inches, or in other words the calorimeter in the locomotive boiler will be 11·11 times less than in the flue boiler for the same power, so that the draft in the locomotive must be 11·11 times stronger, and the ratio of the length of the tube to its diameter 11·11 times greater than in the flue boiler, supposing the heat to be transmitted with only the same facility. The flue of the Nile, as already stated, would require to be 35¼ in. in diameter, if made of the cylindrical form, and 47¾ ft. long: the tubes of a locomotive if 1⅜ in. diameter would only require to be 22·19 in. long with the same velocity of draft, but as the draft is 11·11 times faster than in a flue boiler, the tubes ought to be 246·558 inches, or, about 20¼ ft. long, according to this proportion. In practice, however, they are one third less than this, which reduces the heating surface from 9 to 6 square feet per actual horse power; and this length even is found to be inconvenient. It is greatly preferable, therefore, to increase the calorimeter, and diminish the intensity of the draft.

The arched forms of the bottom and sides of the waggon boiler are not, as is sometimes erroneously supposed, given solely for the sake of additional strength, as the want of proper abutments to the arch, renders them only very slightly available for that purpose; and it is an easy thing to prove that greater strength would be obtained if made the reverse way, or convex outwards, instead of concave. Great strength, however, in a low-pressure boiler, working at only two or three pounds above the atmosphere, is not an object of much consideration: but there is another very important matter to be considered; and that is the position of the heating surface *as respects the fire grate*, or as a recipient of heat, and also as respects the contained water, to which the material of the boiler conducts that heat in order to generate the steam.

As on the proper arrangement of the heating and generating surface it is certain that the excellence of all kinds of steam boilers, both in respect to durability and to economy in fuel, most materially depends, we shall here endeavour to give such a popular investigation regarding it as we hope will serve in some measure as a first lesson or key to the art and mystery of boiler designing, as well as enable the student to appreciate the merits of the common waggon-shaped boiler.

With regard to the boiler bottom forming an arch over the fire, one reason for this construction is very obvious: the heating surface within a given width between the side walls of the furnace is hereby increased; and although this may also be said of a cylindrical boiler, where the arch is downwards, yet in the former the fire and flame are more enclosed within the water, and so far prevented from being expended on a large area of side walls to no useful purpose. The main reason for this construction, however, may be taken to be as follows:—The fire-grate is generally horizontal in its cross-section, and the fuel being generally spread equally thick on the bars in that direction, it follows that the temperature of the furnace chamber, so far at least as it depends on the radiation of heat from the red-hot coal, must be somewhat higher immediately over the middle of the fire-grate than at its sides; and the effect of the heat thus given out by the burning fire against the boiler bottom, supposing the latter to be disposed horizontally across, will be gradually diminished from the centre towards each side, the effect in all cases being directly as the temperature of the surface of the fuel at any given point, and in the inverse ratio of the square of its distance from the boiler bottom. Provided we knew the exact law of the decrease of temperature from the centre to the sides of the mass of the fuel, we could then easily obtain the true form of the curve describing the arch of the boiler bottom, so that the effect of the heat given out from a fire of uniform thickness would be equal over all parts of the heating surface, which would not then be liable to be unduly acted on or overheated in one part more than another. Although any abstruse determination of this is not necessary here, it having been long realized in practice to a much greater degree of perfection than it is possible to acquire in keeping the fire of a uniform thickness, it may, nevertheless, be useful to give a short illustration of the erroneous principle of the contrary practice; that is, of arching the boiler bottom downwards, as in common high-pressure or cylindrical boilers. Supposing then that the temperature of the burning fuel is no greater in the middle than at the sides of the grate, and assuming the average distance of the surface of the fuel below the boiler bottom to be six inches,—say five inches in the centre, and seven at the sides—a very common case,—the effect of the radiated heat against the central portion of the boiler bottom, compared to that of the sides of the furnace, will then be as the fractional numbers $\frac{1}{25}$ and $\frac{1}{49}$, or nearly as two to one: and this great disparity of effect is of course still farther increased by the greater heat of the fire at the middle of the grate.

Under such circumstances we need not to be surprised at the very great liability of the bottom plates of cylindrical boilers to become gradually overheated and finally burnt out, while those towards the sides are very little injured. In waggon boilers, it is true, the converse of this does sometimes take place; that is, the seating plates, or those immediately adjoining them, are found occasionally to deteriorate and become injured sooner than those in the crown of the boiler bottom. But this result only corroborates the truth of the general principle we are contending for; at the same time proving the necessity of attending to those apparently unimportant mechanical details so commonly overlooked by the scientific engineer; for the defect always arises either from the crown of the arch being too high, or by having the fuel too thick on the bars, so that its radiating surface is too near the sides of the boiler bottom; or otherwise in consequence of the fire-grate itself being placed too high; whereas no situation of the grate whatever can prevent the injurious action of the fire against the inverted arch of a cylindrical boiler.

The manner in which the position of the heating surface affects the *generation* of the steam, is best understood by considering that it can only be by a certain tendency to overheat, or—to use the more ambitious language of philosophical theorists—to overcharge the substance of the heating surface with caloric, that any heat can be imparted to the water within the boiler; and the greater the difference of temperature between one side of the boiler plate and the other, the more rapid ought to be the communication in order to preserve the latter uninjured. Now, if instead of the heating surface being in a position approaching to the horizontal over the fire, as described above, let us suppose it to be placed in a perpendicular direction with respect to the fire grate, and let us farther suppose the burning fuel to be in immediate contact with it, as in fact it usually is, in most of those boilers with internal furnaces, such as marine and locomotive boilers, and in all those called fire-box boilers,—the effect then must be that all the particles of water that come in contact with the *inside* of this heating surface, or *generating* surface, which are converted into steam, will rise to the surface of the water; and by doing so, if in sufficient quantity, they form a continually ascending current or thin stratum of vapour, interposing itself between the water and the plates of the boiler, thus creating two evils at once; first, the prevention of a sufficiently rapid transference of the heat of the plate to the water, excepting only at the lowest point of the effective heating surface, where the fire is in immediate contact with the plate, thereby diminishing the evaporative power of the boiler; and secondly, the effectual prevention of all proper access of the water to those portions of the generating surface immediately above the heated point. The plates in those parts are therefore sure to get overheated and burnt out in a comparatively short time. This is in fact precisely what takes place in many fire-box boilers, and, to a certain extent, in all boilers that have internal furnaces or flues with *flat sides*, unless those sides incline somewhat to one another, to facilitate the escape of the steam from the heated surface.

CHAPTER II.

FURNACES.

It is, of course, impossible that we should attempt any enumeration of the various kinds of steam engine furnaces that at different times have been brought before the public, for their name is legion, and very few of them have approved themselves of any utility: but we shall give a brief sketch of some of the principal examples. The purpose of all these schemes has been to consume the smoke generated in all ordinary furnaces in which bituminous coal is burned; and although the means by which this is proposed to be done are diverse and innumerable, yet the whole of the plans may be roughly classed under two general heads. In the first of these the smoke is proposed to be burned by passing it over or through a fire or other incandescent substance, and in the second the same end is proposed to be attained by admitting a stream of air into the flue or furnace, by which the combustion of the inflammable parts of the smoke may be effected. Each of these methods, however, presumes that there is enough oxygen mingled with the smoke for the purposes of combustion, but in the one case the necessary supply of air has to make its way through the fire—which it can easily do if the fire be thin, and the draught vehement—while in the other case an orifice is specially provided for its admission.

One of the first schemes for the prevention of smoke is that of Papin, who proposed to make the smoke descend through the fire;—the necessary draught for that purpose being maintained by means of his centrifugal blower. This is a very feasible scheme, and one which we are convinced would be found effectual if carried out judiciously in practice, but the impediments presented by the coking of the coal and the absence of an effectual exhauster has hitherto prevented its success. This scheme was revived by Delasme, and was afterwards carried into effect for house stoves by Franklin, but various inconveniences attendant on the lighting of the fire, and other technical points, has prevented Franklin's stove from reaching into any considerable adoption.

In 1785 Mr. Watt took out a patent for obviating the smoke of steam engines by placing the coal in an upright conical tube or hopper fixed in the brickwork of the boiler, immediately behind the furnace door, and causing a stream of air to rush through the furnace door for maintaining the combustion. In this plan, there are no fire bars, but the fire rests upon a brick arch, and the whole of the air that reaches the fire has to pass through the coal that has not yet entered into combustion. By this means the gases, evolved from the coal by the application of heat, mixed with air, are passed through and over the ignited fuel, and are thereby consumed; or they may be passed through hot funnels or pipes which will accomplish nearly the same purpose. This plan, though ingenious and in one sense successful, was relinquished by Watt, on account of the difficulty of dealing with caking coal, which by its concretion prevented the due admission of the air; and he adopted in its stead the plan of a dead plate between the furnace door and the fire bars, upon which the coal is first coked, and is then pushed back upon the bars to undergo combustion. This plan, which is still used by Messrs. Boulton and Watt, is very effectual in preventing smoke with careful firing: we give a drawing of it as at present used by Messrs. Boulton and Watt, in another part of the present chapter.

In 1796, Mr. William Thompson of Bow Lane took out a patent for consuming smoke by admitting a stream of air behind the bridge, which appears to have been the first plan brought into use on that principle. The same species of furnace was afterwards patented by Sheffield, Gregson, and others with trivial variations, and during the last few years a host of patents have been taken out for this kind of furnace, some of them under very imposing names, but none of them can be said to have been successful. One great impediment to their success has been the difficulty of apportioning the quantity of air admitted to the varying wants of the fire; for after the furnace has received a charge of coal a greater quantity of smoke is produced than at other times, and a considerable admission of air becomes necessary; but if the air valve be regulated so as to supply this quantity, it will supply too much when the smoke has passed away, and unless a more sedulous attention be given by the fireman than can be expected in practice the quantity of air admitted to the furnace will generally either be too great or too little, and a defective performance must therefore be the consequence. Some of these facts we believe we have stated already; but it is necessary to repeat them here to explain that when the fire is supplied with coal by means of Stanley's fire-feeding machine, or any other self-acting mechanism which makes the production of smoke uniform, it becomes possible to adjust the air valve with great nicety to the requirements of the fire; and even in other cases the due adjustment of the supply may be approximated to by means of a very ingenious mechanism invented by Mr. Murray of Leeds, and described in the London Journal for 1821. In this plan the air supplied to the fire for burning the smoke passes through a tube furnished with a throttle valve, which valve is opened by an attachment to the furnace door, and closed by means of a vane wheel, like a smoke jack, inserted in the mouth of the tube, and which is moved by the current of air passing through the tube into the furnace. When therefore the furnace door is opened and a charge of coal put upon the grate, the throttle valve is opened by its connection with the furnace door, and a sufficiency of air enters: but the entering air, by turning the vane, gradually closes the valve as the generation of smoke diminishes; and by a proper adjustment of the mechanism to the quality of the coal employed and the quantity introduced at a time into the furnace, a very nice regulation of the air may be accomplished. At the same time it must be stated that furnaces which admit air into the flue or furnace, even when provided with a mechanism of this kind, have not been successful in practice. Mr. Pritchard of Leeds, in 1821, proposed to accomplish the same end as was attained by Mr. Murray's mechanism, by means of a piston descending by gravity in a cylinder of air, the piston forcing out the air through a small orifice. The desired effect, it is obvious, can be produced in many ways, which will at once occur to our readers, and which it would, therefore, be superfluous to describe.

An experiment a short time since was tried at Soho, with the view of testing the efficacy of C. W. Williams's Argand furnace, as it is called, which is a furnace for burning smoke by the admission of air into the flue by a number of orifices, or for accomplishing the chemical combination of the gaseous constituents of coal with the oxygen of the atmosphere, as we suppose would be the definition in Mr. Williams's pompous phraseology. The ordinary boiler in use at Soho was fired with one kind of coal for a period of four months, and the effect and consumption were carefully noted. Mr. Williams's improvements were then applied, and with the same kind of coal, the same man firing, and all other circumstances as nearly as possible identical, the consumption, Messrs. Boulton and Watt inform us, was nearly a pound per horse power per hour *more* than before. The furnace in its ordinary form, which was with a dead plate fitted before the furnace as in Messrs. Boulton and Watt's usual plan of land boiler, produced no smoke; whereas after Mr. Williams's improvement a good deal of smoke was sometimes produced, though usually there was none.

One very ingenious method of consuming coal so as completely to obviate smoke consists in lighting the coal on the top; and a contrivance known as Cutler's grate was some years ago introduced for accomplishing this object in the case of house fires. There is a difficulty, however, in introducing fresh coal beneath the ignited mass, and the plan of a piston for raising it up to the fire is inconvenient. In 1815 Mr. William Moult contrived a furnace on this principle, in which he brought the flame over the coals, the coals being laid upon a dead plate; but it does not appear that this plan has met with much encouragement or success. In 1815 Mr. William Losh of Newcastle took out a patent for a combination of double furnaces; in which, by a suitable arrangement of dampers, the smoke from one of the furnaces was made to pass into the ash-pit of the other; and mixing there with the atmospheric air, and ascending through the fire, it was consumed. The furnaces were of course fired alternately, so that one was bright while the other was smoky. This is one of the most effectual methods of consuming smoke that has yet been contrived, but the shifting of the dampers is troublesome, especially as they require to be strong and heavy, to withstand the heat.

We pass over the plans of Roberton, Johnson, Parkes, Coombs, Stretton, and a host of others, as there is nothing in their schemes of much novelty or utility. In the report of the Smoke Committee of the House of Commons of 1819, a plan is given by Mr. John Walker, junior, of an engine furnace with a coke oven attached; the design being that the coal should first be coked in this oven, and then transferred to the grate to be consumed.

This scheme is not very practicable, but we believe something of the kind is now being revived by a French engineer at Manchester, the details of which may be such as to give it a better chance of success.

The two most important projects in smoke-burning furnaces appear to be the revolving grate usually known as Brunton's and Stanley's fire-feeders, which last are much employed in the manufacturing districts. The revolving furnace was described by Mr. John Steel, of Dartmouth, before the Smoke Committee of the House of Commons in 1819, and in December of the same year the plan was patented by Mr. Brunton; so that it does not appear very clearly to which of these mechanists the invention is due: but, whoever be the inventor, the plan is the best, in our opinion, yet devised for obviating smoke, and, if applied judiciously, can hardly fail to be productive of an important economy. Stanley's plan, which was patented in 1822, consists in the application of a hopper to the furnace into which the coal is thrown, the neck of the hopper being furnished with grooved rollers put into revolution by the engine, which seize the pieces of coal that exceed the size regulated by the distance asunder of the rollers,—and which may be adjusted by a screw,—and drop them on an iron plate underneath, from whence they are projected by an arrangement resembling a revolving fan, which scatters the pieces equally over the fire. The gearing, which gives motion to this apparatus, is so contrived, that as the engine becomes quicker its effective speed becomes less, and the quantity of coal supplied to the furnace, therefore, just comes up to the demands of the engine for steam. A drawing of this machine, as applied at the present time to boilers in Lancashire, will be given in one of the plates of the present work, which will make the nature of the apparatus more intelligible than the most elaborate description could hope to effect. A sketch of the revolving grate in its present improved form, as applied by Messrs. Boulton and Watt a year ago to the steam furnaces of the Bank of England, is given at page 52. of the present work; and we must reserve what we have to say farther of the contrivance in question until we come to the description which that representation demands.

In 1824 a patent was taken out by Mr. Humphrey Jeffrey, of Bristol, for a plan of condensing smoke and metallic vapours by means of a shower of water, which has been introduced with success in many cases in practice. In order to carry into effect this plan, it is necessary to have two or more chimneys, each closed at the top, and connected together by a cross flue at the top, so as to form a combination resembling the Greek letter Π (pi). The smoke or vapour ascends one of these stalks, and passes into the upper part of the other by the horizontal flue, where it meets a shower of water descending from a tank on the top of the second stalk, by which it is carried downwards, and it passes off with the water into a drain. We do not think it necessary to resort to this plan for the destruction of smoke, as we think that end attainable by more economical means; but we think the plan is one of much value for condensing the insalubrious vapours of vitriol works, copper smelting furnaces, and other such manufactories of asthma, and that its use should be made compulsory in such cases. Several newly-fledged projectors have been endeavouring, we find, to attract the public attention to this plan under some unimportant modifications, by pretending that it is a novelty of their own device: but the plan is an old one, of which the patent has for some time expired; and any one is free to use it who feels so disposed. It will be expedient, in some cases, to make the smoke or vapour ascend a stalk several times, or rather to make it ascend several stalks in succession, in order to receive in each returning stalk a fresh shower of water; and it is important that the final exit of the gaseous matter should be at the top of a stalk, which may be made higher than any of the others. A good method of forming a combination of this kind would be to cause the smoke and vapours to traverse a series of upright iron cylinders connected alternately at the top and bottom, with a shower of water in each descending cylinder, and the last one might be carried to a sufficient elevation to constitute a chimney.

In 1824 Mr. Evans, of Queen Street, Cheapside, took out a patent for obviating smoke by admitting steam into the furnace. This plan has been often tried: it was introduced into the Edinburgh gas-works many years ago by Mr. Nasmyth, of Patricroft, and has since been revived by Mr. Ivison, of Edinburgh: but we do not anticipate that the plan of admitting steam into the furnace or ash-pit will reach any high measure of success so far as relates to the prevention of smoke, though for other purposes its admission may in some cases be advantageous.

Of all the projectors in the field of smoke-burning there is no more assiduous veteran than Mr. John Chanter. He has a great number of patents for different kinds of furnaces; and, indeed, his plans vary so frequently, that it is difficult to know what they are; and we question whether he is perfectly confident on this head himself. Mr. Chanter, we should say, is a person of a wavering disposition, the effect in many cases of exuberant ingenuity; but, however this may be, we do not think any of his plans are likely to approve themselves of much utility in practice. Mr. Samuel Hall and Mr. Joseph Williams have plans for burning smoke by the admission of hot air into the flue or furnace, and Messrs. Drew, Rodda, and others, have plans which nearly resemble some of those that we have already described. Mr. Cheetham, of Staley Bridge, accomplished the combustion of the inflammable parts of the smoke by drawing it by means of a fan out of the upper part of the flue leading to the chimney, and sending it, mixed with atmospheric air, into the ash-pit, to ascend through the fire. The carbonic acid, which, by virtue of its specific gravity, occupies the lower part of the flue, is not returned to the fire, but passes at once to the chimney, and thus maintains the draught.

About four years ago certain contrivances for obviating smoke were applied in some of the vessels of the Peninsular Steam Company, which we may here explain. *Fig.* 30. represents the method adopted in the steamer William Fawcett. The whole of the furnaces were arranged in pairs, and an opening was cut through the waterspace intervening between each pair of furnaces, so as to permit the smoke from the one to pass through a pipe fitted at the furnace mouth into the ash-pit of the other, and mixing there with atmospheric air, and ascending through the incandescent fuel on the bars of the second furnace, it was consumed. One furnace thus operated as a retort while the other acted as a furnace, a damper extending between the double bridges shown in the horizontal section being closed when the furnace received a charge of coal so as to convert it into a retort for the time being. As soon as all the gas was expelled from the coal thus introduced the damper of this furnace was opened so as to convert it into an active furnace, and the damper of the other furnace was closed to be in readiness to receive a charge of coal, and no smoke was visible at the chimney while this action proceeded. It is troublesome, however, in practice to shift these dampers; and altogether the plan is not so good as many others that have been brought under the notice of the public. *Fig.* 31. represents the method of diminishing smoke introduced into the steamer Tagus. Two Venetian bridges were formed of tiles laid at an angle about three quarters of an inch apart, the bridges themselves being about a foot apart, with a vacant space between them. These tiles of course became very hot by the flame passing between them; and by keeping a thin fire on the bars, so as to enable a sufficiency of oxygen to find its way through the burning fuel to accomplish the combustion of the inflammable gases during their passage between these hot surfaces, the smoke was very completely extinguished. The bridges were built upon an arch closed by a door, so as to enable a person to get into the flues without taking the bridges down. We think that a succession of bridges of this description, with a furnace lined with fire-brick, a good draught, thin fire, and very narrow furnace-bars widely set, would accomplish the combustion of smoke very completely. It would be better if the tiles, instead of being flat, were semicircular, for the hot current would be thus made to reverberate; and conflicting draughts and eddies have a powerful effect in aiding the combustion of smoke.

Fig. 30.

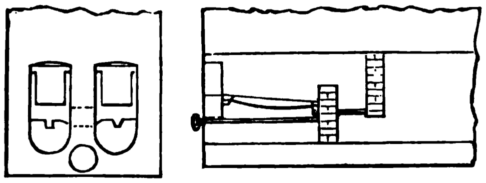


Fig. 31.

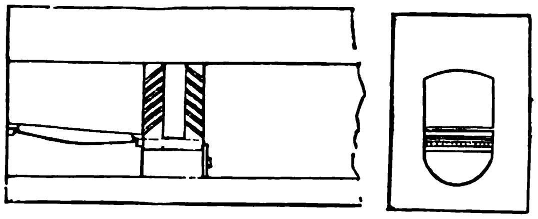
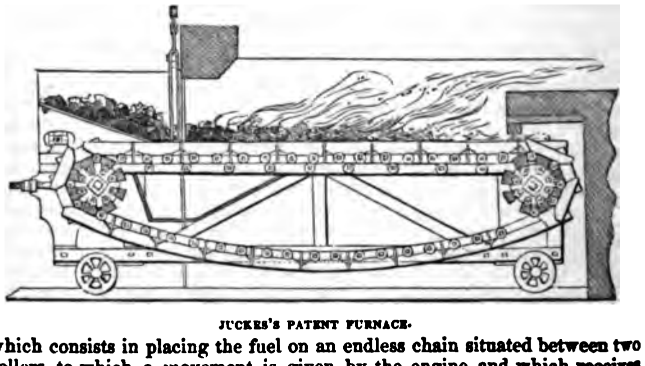


Fig. 32. represents the furnace of Mr. John Juckes, the peculiarity of which consists in placing the fuel on an endless chain situated between two rollers, to which a movement is given by the engine, and which receives the coal at the furnace mouth, and delivers the clinkers and ashes at the other end of the furnace. This we look upon as a good plan in many respects, but the mechanism, we fear, must be expensive to keep in repair.

Fig. 32.

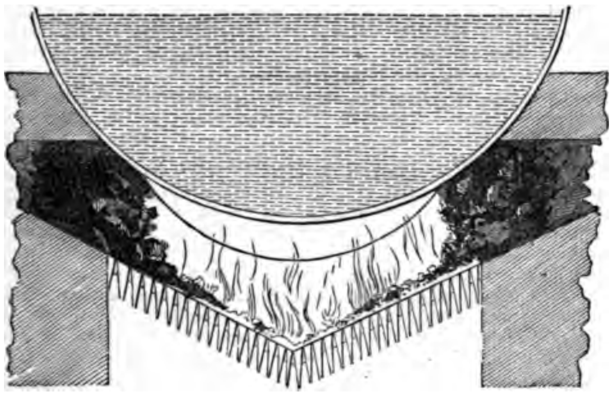


JUCKES'S PATENT FURNACE.

The endless chain of fire bars and its sustaining rollers are carried on a wheeled frame resting on rails, so that the fire may be at any time withdrawn altogether from beneath the boiler. The furnace door is of that description which slides up and down, and the degree of its depression regulates the thickness of the coal on the bars of the grate.

Fig. 33. represents the furnace of Mr. Nathan Waddington, in which the bars are arranged in two inclined planes, the coal at the upper part being slowly coked previous to its descent upon the bars; and the space between the central bars where the two inclined plans meet may be kept open to admit enough air to accomplish the combustion of the gases. It does not strike us that this furnace is a very manageable one, and we do not find that it has met with any considerable adoption. The plan of firing at the sides, moreover, is such as to be inapplicable in most situations.

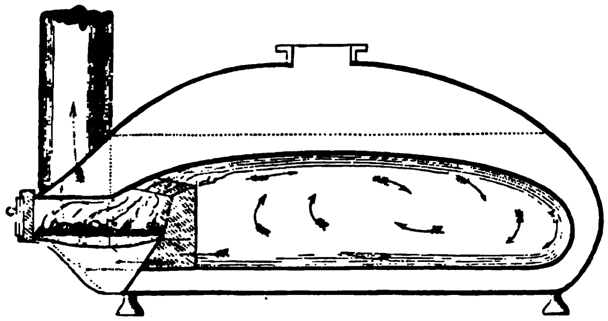
Fig. 33.



WADDINGTON'S PATENT FURNACE.

Fig. 34. represents the furnace of Mr. John Smith, of Kingstown, near Dublin, in the form exhibited by him before the British Association at Manchester. The boiler is constructed on what has been called the oven plan, which is without flues, and the flame and smoke pass from the furnace into a large central chamber, where the inflammable parts of the smoke, by being more thoroughly mixed with oxygen, which is also present, readily enter into combination. This plan of boiler, however, is very objectionable, from its deficient strength; and altogether we have not very sanguine hopes of much benefit being realized by Mr. Smith's invention.

Fig. 34.



SMITH'S BOILER AND FURNACE.

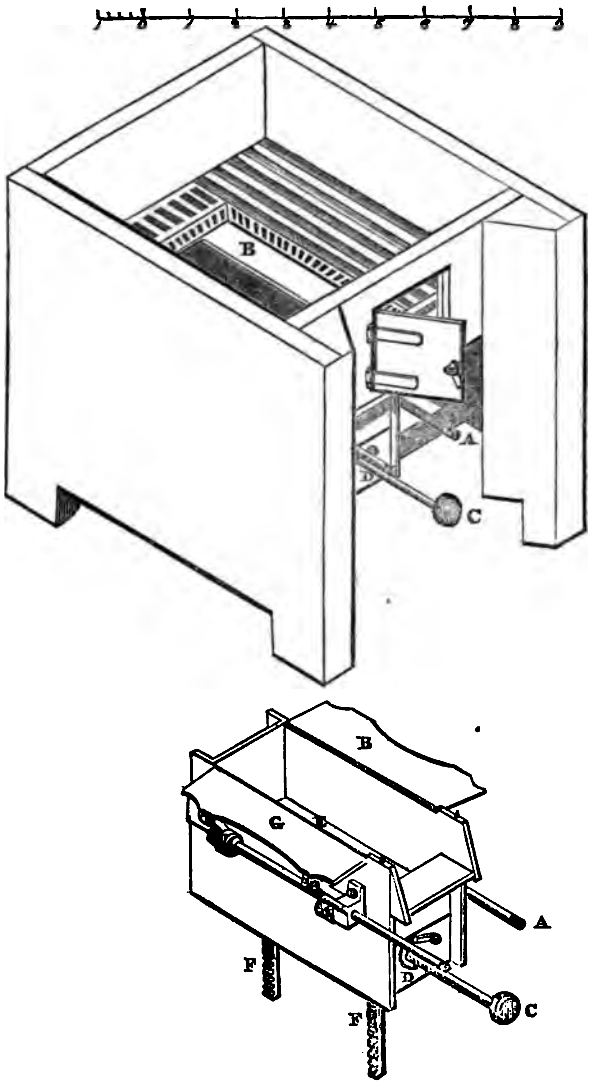
Of all the smoke-burning schemes that have been brought forward, at this or at any other epoch, there is none that has been ushered before the public with more noisy pretension than that of Mr. Charles Wye Williams; yet the project is one of very slender merit; and so hard are its perfections to be discovered that Mr. Williams, it appears, has had to write an octavo volume to point them out. This furnace, which we need not delineate, differs in scarcely any respect from the previous schemes of Gregson and others, except in the single feature of admitting the air by many holes instead of by two or three: but even this innovation had been brought into use before the date of Mr. Williams's plans; though, indeed, it is hardly worth while to rob him of the praise of this originality, seeing how small must be its value. Mr. Williams says, his is not a smoke-burning furnace; and we are sorry to hear it: it is certainly a smoke-generating furnace; and if the smoke be not burned, it must pass off unconsumed. We know, indeed, that it will be argued that it is gas, and not smoke, that this furnace produces; and we have not the least objection to call the aeriform matter passing over the bridge by that name, if it gives Mr. Williams any gratification. But in that case it is obvious that it must have been gas that Gregson and others of his fraternity burnt also; so that Mr. Williams's scheme is as far from enjoying any distinction on this score as ever, whatever name be given to its gaseous products. It is no doubt better, if air is to be admitted into the flues of a boiler, that it should be let in by many orifices instead of by one or two; and it would be a further improvement, we think, to subdivide the smoke in the same manner. But in whatever way the air be admitted, the aeriform matter to which it is let in is the same in Mr. Williams's furnace as in any other; and to pretend that a mere difference in the number of holes can change its nature is just about as absurd as it would be to allege that water would be turned into wine by pouring it through a sieve. Indeed, if it were gas, and not smoke, that Mr. Williams's furnace produces, the boiler would continually be in danger of explosion; for every one knows that gas when mixed with air will explode if a light be applied, and a train of gas and air laid in the furnace and flues would be as dangerous as a train of gunpowder. As, therefore, Mr. Williams's furnace, notwithstanding all its scientific pretensions, is a mere smoke-burning furnace, that operates by the admission of air into the flues, it has to be considered with others of the genus to which it belongs; and as Mr. Williams has loudly condemned the whole tribe of smoke-burning furnaces, it is needless for us in this instance to repeat the condemnation.

We have already stated that there are some advantages peculiar to this furnace; but there are certain disadvantages peculiar to it also. The small air-holes are very liable to choke up, and the dispersers speedily get burned out, if made of cast iron, while if they be made of fire-brick they are very liable to get broken in sweeping the flues, and in the case of the contracted furnaces of marine boilers even by the rakes and slices of the fireman. The alternate heating and cooling again of the iron of the furnace in those situations which are exposed to the influence of the dispersers—for when there is much smoke in the furnace it will be flame that proceeds from them, and when there is little it will be cold air—has a tendency to injure the texture of the iron, and give rise to cracks and blisters. Under such influences the iron will be more disposed than in common boilers to give way; and we have heard of several instances of boilers having been damaged from this cause. Indeed, the question has been raised, whether the explosion a short time since, of Brook's mill at Boulton, was not owing to the injuries the boiler sustained from Williams's furnace, which it appears had been in operation in that instance. While, however, it is necessary that we should state these defects, we do not by any means concur in the utter condemnation this scheme has received in some quarters. It is the best furnace, we think, of that class which operate by the admission of air into the flues, or at least is capable of being made the best by a due regulation of the details: yet this is only a slender excellence, as we look upon all that class of furnaces as impossible in practice. We must say, too, that we do not see how Mr. Williams's attempts to pass off his scheme for what it is not, and for what he must have *known* it is not, can be reconciled with that ingenuousness that is necessary to the character of a gentleman. The title of the Argand furnace can only tend to mislead the unwary; and it is as idle to pretend that its operation is therefore like that of an Argand lamp as to maintain that if it were only called a Circassian furnace its fumes would improve the complexion. The furnace is, in truth, one of much mediocrity, and will not, we are persuaded, come into any considerable use, whatever be the advertisement and agitation. The disadvantages are too many, and the benefits too few, for the realisation of this result; and the experiments at Soho, which we have already mentioned, have, in our judgment, rung this project's funeral knell.

Fig. 35. represents the furnace of Mr. George Godson, which has lately been applied at Woolwich and other places. The principle of this plan is identical with that of Cutler's grate, already described. The coal is introduced into a box beneath the furnace, provided with a moveable piston, on the top of which the coal lies. There are two sliders for closing the opening in the grate usually occupied by the box at such times as the box is withdrawn to be replenished with coal; and when the full box is replaced these sliders are drawn back, and the coal in the box ignites at the top. As the coal burns away, the piston is raised up in the box to maintain the burning fuel at the same level; and the gas expelled from the coal by heat is consumed by passing through the incandescent fuel on the bars. This species of furnace, indeed, is a sort of coal-torch, and its whole advantage lies in the gases of the coal being presented for combustion, without being intermingled with the carbonic acid and nitrogen, resulting from the combustion of the coaky part of the fuel—the air being admitted through a number of orifices around the top edge of the torch to accomplish the combustion of the gases. It would be difficult, however, we fear, in a large furnace, to mingle the air with the gases sufficiently, or duly to regulate the quantity admitted in such cases. In the case of a house fire there is no difficulty upon these points; for as the fire is but small the air has an easy access, and an excess of air in all open fires ascends the chimney: but in the case of a furnace for a steam engine an excess of air acts most perniciously by cooling the boiler; and a furnace which involves such a risk is not likely to be successful. The raising of the coal by manual labour applied to the piston is another objection to this plan, though by no means a serious one, as it would be an easy thing to raise the piston by the engine. It may aid the comprehension of the plan if we give some letters of reference. A and D the handles for moving the slides B and G. C the handle for moving the racks F, F, which raise the piston in the box E.

There are several plans for burning anthracite coal in ordinary furnaces that have at various times been brought forward with different degrees of success; and we may for a moment glance at some of these projects. Mr.

Fig. 35.

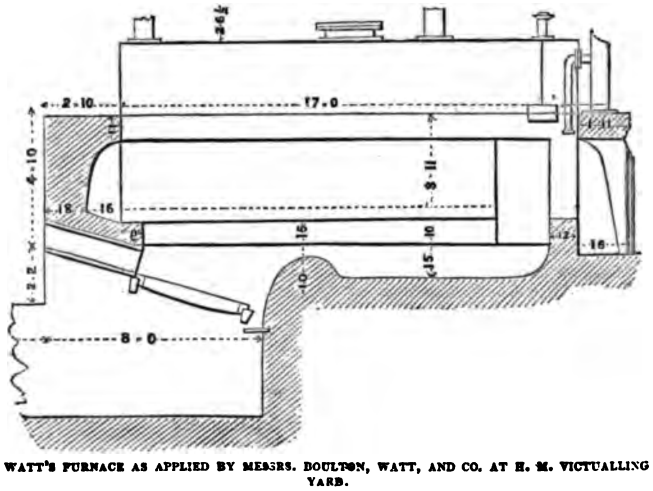


GODSON'S FURNACE.

Howell, of Philadelphia, took out a patent, in 1828, for a very judicious furnace of this description, the chief peculiarity of which was, that the heat from the coal was prevented from entering the water in the wake of the furnace by lining the furnace with fire-brick; and the temperature was thus kept up to a point sufficient for the accomplishment of the desired object. A small steamer, called the Anthracite, was for some time run upon the Thames, in which the furnace was so constructed that the coal was gradually made very hot before entering into combustion on the bars; and the plan of Mr. Kymer, for accomplishing the combustion of anthracite by means of a fan-blast, and by using bars with a trough of water under each, is well known. The water preserves the bars from being burnt out, and the steam which arises from it by passing through the fire carries the heat into the flues and diffuses it more effectually; whereas, by burning anthracite without steam, the heat is too local, and is liable to damage the iron of the boiler. There is not much difficulty, however, in burning anthracite beneficially according to our views of the matter without these water troughs, if the furnace be made very large, be lined thickly with fire-brick, and a very thick stratum of incandescent fuel be kept upon the bars. The difficulty attending its use arises from the circumstance of its being less easily kept alight than ordinary coal,—just as lighted coke is more difficult to keep alive than lighted charcoal; and the difficulty is to be got over by the same method that the difficulty was surmounted of using coke instead of charcoal in smelting furnaces, at a certain period in the history of our iron manufacture,—the employment of larger furnaces.

We have now, then, enumerated most of the smoke-preventing furnaces that have occupied a prominent position in the public eye, though there are a vast number of analogous schemes, the names even of which we have been unable to mention: and the question very naturally arises at this stage of our progress, is there any really feasible plan for obviating smoke that would justify the legislature in passing a stringent law to enforce the extirpation of such a nuisance? We reply, without hesitation, that there are several such plans, and we shall here enumerate those which we think the best calculated to accomplish the desired object. The boilers of the Cornish mines produce very little smoke, in consequence of the slow combustion of the coal there practised; and a slow combustion and a large furnace and boiler have the effect of mitigating the evil of smoke to a great extent. Much of the smokeless efficacy, however, of the Cornish boilers arises from the use of Welsh coal, which contains but little bitumen, and does not produce much smoke; and there is much less hardship in compelling smoke manufacturers to use this coal if they feel disposed to reject other smokeless expedients, than to make the public still suffer the infliction of so great a nuisance. A mixture of coke and anthracite, too, may be burned beneficially in any furnace of the common kind: and the expense of such a mixture is not so great as to be a reasonable barrier to its employment. Watt's plan, again, of coking the coal on a dead plate previous to its introduction to the furnace, is very effectual, with judicious firing; and at the chimney of the engine at Soho, where this plan has been in use for half a century, smoke is never to be seen. *Fig.* 36. is the representation of a 30-horse boiler, erected by Messrs. Boulton, Watt, & Co., for an engine made by them at H. M. Victualling Yard at Deptford. The dead plate, it will be observed, runs in the same line as the bars, and the inclination at which both lie facilitates the transmission of coal from the one to the other. The gases arising from the green coal in passing over the fire are consumed, enough air being in the furnace to accomplish their combustion.

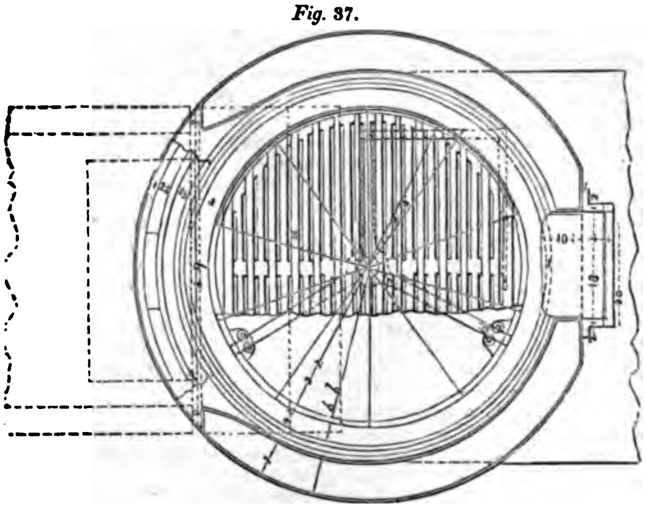
Fig. 36.



WATT'S FURNACE AS APPLIED BY MESSRS. BOULTON, WATT, AND CO. AT H. M. VICTUALLING YARD.

The best plan, however, for burning smoke that we are acquainted with is the revolving grate we have already mentioned, as improved by Messrs. Boulton and Watt, and applied by them to the boilers of the engines employed in the Bank of England. This apparatus is shown in *figs.* 37., 38., and 39.; and its structure is so fully shown by these delineations, that a brief description must suffice. The circular grate, supported on an upright spindle, is put into revolution by means of wheel-work, and

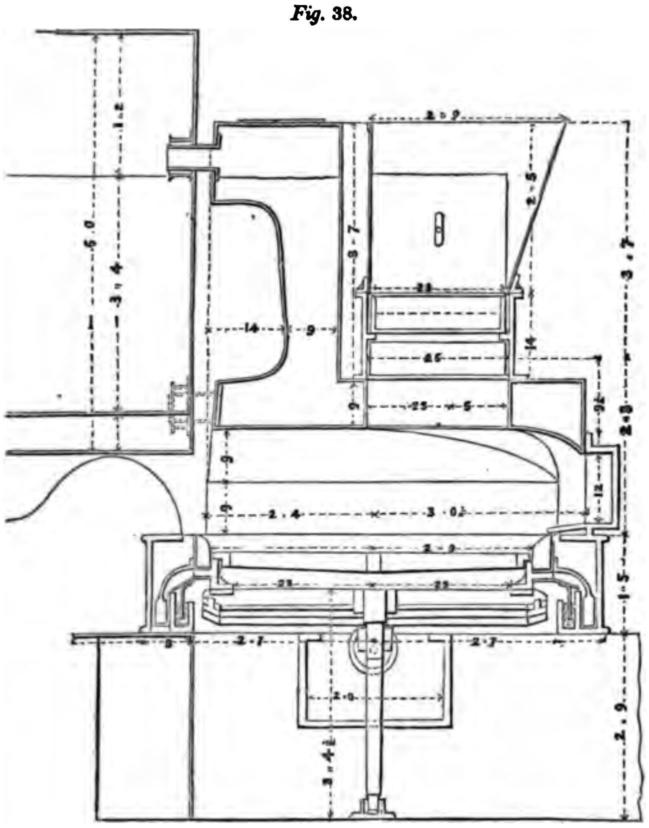
Fig. 37.



REVOLVING GRATE AS APPLIED BY MESSRS. BOULTON, WATT, AND CO. IN THE BANK OF ENGLAND, 1848.
Horizontal Section.

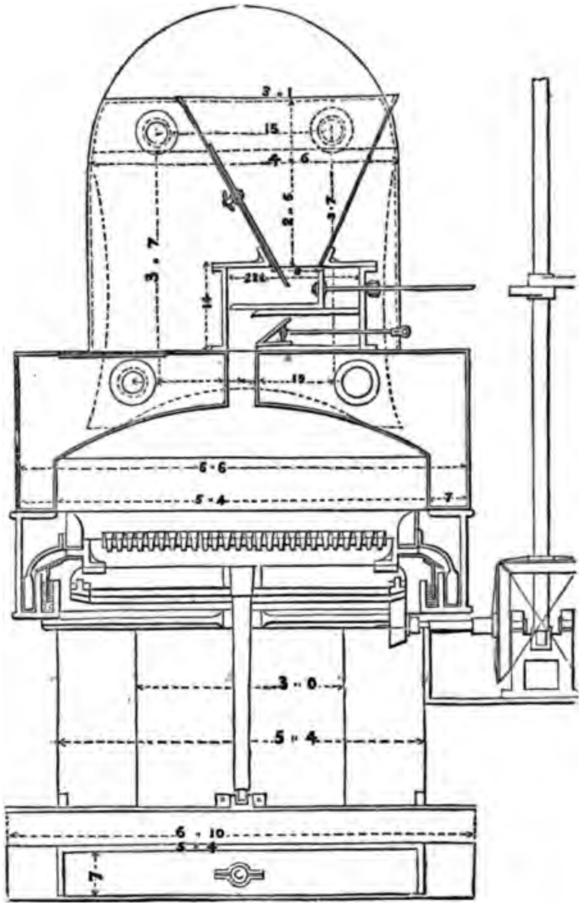
the coal is dropped upon the grate from the bottom of a hopper shown *figs.* 38. and 39. The grate is covered with a supplementary boiler made low so as to admit of the hopper being placed upon the top; and the hot air, proceeding from the fire after acting on this boiler, proceeds through the flues of a common waggon-boiler to the chimney. A ledge of brick surrounds the grate to retain the coal upon it; and nearly underneath the brick a projecting plate of iron runs in a groove of sand so as to prevent any escape of air into the furnace. A box of cast-iron is set in the brick-work to contain the bevel wheels, which give motion to the grate; and the large wheel, by which the motion is imparted to the grate, is situated immediately beneath the bars, with its teeth protected, by the ring of brick above, from the falling ashes. The outlet for the products of combustion is, as will appear by a reference to *fig.* 38., on the opposite side of the grate to that upon which the coal is admitted, and the gases extricated from the coal by passing over the incandescent fuel on the other parts of the grate are consumed. It would be an improvement, we think, if the supplementary boiler were done away, and the grate placed in a furnace of a similar shape to that of a locomotive fire-box on the construction of Messrs. Bury and Co.; and this furnace should be lined with fire-brick; or a better plan still would be to make the boiler with perpendicular locomotive tubes, after the fashion practised by Messrs. Rennie, and described in another part of the present treatise—a large fire-tile block, perforated with holes opposite the tubes, being interposed between the tube plate and the fire, both to shield the tube plate from injurious heat and to make the combustion more perfect within the furnace. Boilers constructed on this plan would emit no smoke, would occasion no trouble in firing, and would operate with a moderate consumption of fuel.

Fig. 38.



REVOLVING GRATE AS APPLIED BY MESSRS. BOULTON, WATT, AND CO. IN THE BANK OF ENGLAND, 1843.
Longitudinal Section.

Fig. 39.



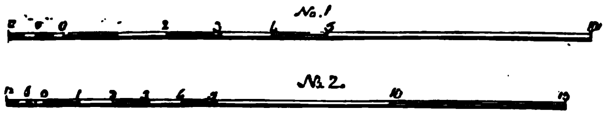
REVOLVING GRATE AS APPLIED BY MESSRS. BOULTON, WATT, AND CO. IN THE BANK OF ENGLAND, 1843.
Transverse Section.

CHAPTER III.

VARIETIES OF BOILERS.

Before proceeding to give tabulated computations of the fire and flue surface of boilers, the performance of the different varieties with respect to consumption of fuel, and such other particulars relative to their performance as will be a guide to the engineer and show forth the best methods of construction, we think it expedient to give drawings of some of the boilers of which these particulars are to be determined, both to render our tabulated results clearer than they could otherwise be, and to furnish the engineer with examples to avoid or imitate. These delineations are all made to a scale, and on the more important of them the sizes are also marked; so that these wood-cuts may serve all the purposes of working drawings — half an inch either in excess or defect in the length of a boiler being a thing of no importance. Subjoined are given two scales, the one or the other of which is applicable to such of the boilers represented as are not measurable by any of the scales in common use. A notification will be given of each case in which either of these scales is to be applied.

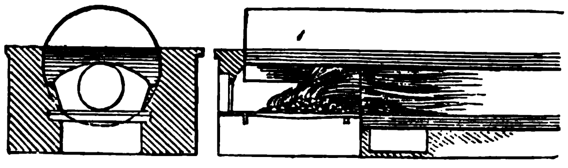
Fig. 40.



SCALES.

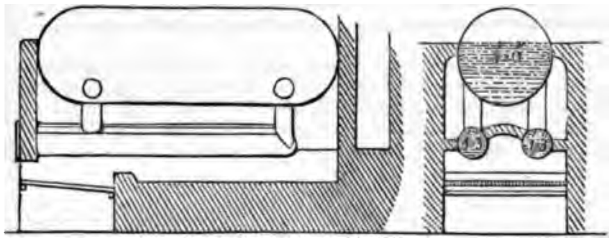
Fig. 41. represents the Butterly boiler, which is much used in the manufacturing districts; and *fig.* 42. a species of boiler called the French boiler, in consequence of being of French origin. This boiler is a good deal used in Lancashire, and is spoken of highly. We think it more conducive to accomplish perfect combustion than any boiler with which we are acquainted, on account of the interposition of an arch of brick between the furnace and the boiler bottom,—two tubes, connected to the boiler by means of necks, being the whole heating surface to be found in the furnace. The smoke, it will be observed, first passes to the end of the furnace beneath the brick arch, and then, rising up, comes forward to the front of the boiler in the space left between the brick arch and the boiler bottom, after which it passes, by the plan of a split, along the boiler sides to the chimney. The anticipation, looking to the peculiar construction of this plan of boiler, would naturally be, that the tubes situated above the fire would be liable to burn out from the accumulation of depositure in them, and that the steam could only ascend to the water surface with great difficulty, and at the expense of a great agitation of the water, which might occasion priming: but we have not been able to learn that these evils have arisen to any inconvenient extent in practice; and we find manufacturers and others persevering in the use of this species of boiler, which says much in its behalf.

Fig. 41.



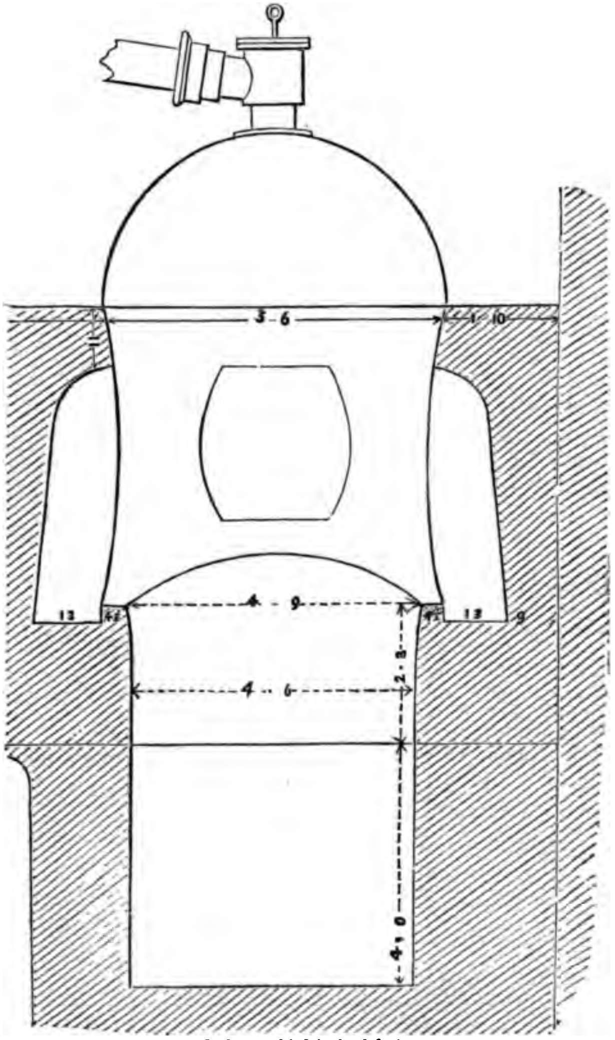
BUTTERLY BOILER.

Fig. 42.



FRENCH BOILER.

Fig. 43.



Scale one third inch=1 foot

TRANSVERSE SECTION.

Fig. 43. is a transverse section of a 30-horse-power waggon boiler of the kind employed by Messrs. Boulton and Watt. This boiler will serve as a type of its class. We shall hereafter give the length, breadth, height, and surface for the different powers.

Fig. 44. represents the boilers erected by Messrs. Maudslay and Field at the London terminus of the Blackwall Railway. One set of them is on the Cornish plan, and the other of the ordinary marine construction; and with the same amount of surface, and all other circumstances as nearly as possible the same, the Cornish have been found to be the *least* effectual at the pressure at which these boilers are worked.

Fig. 44.

BOILERS AT THE BLACKWALL RAILWAY, BY MESSRS. MAUDSLAY, SONS, AND FIELD.

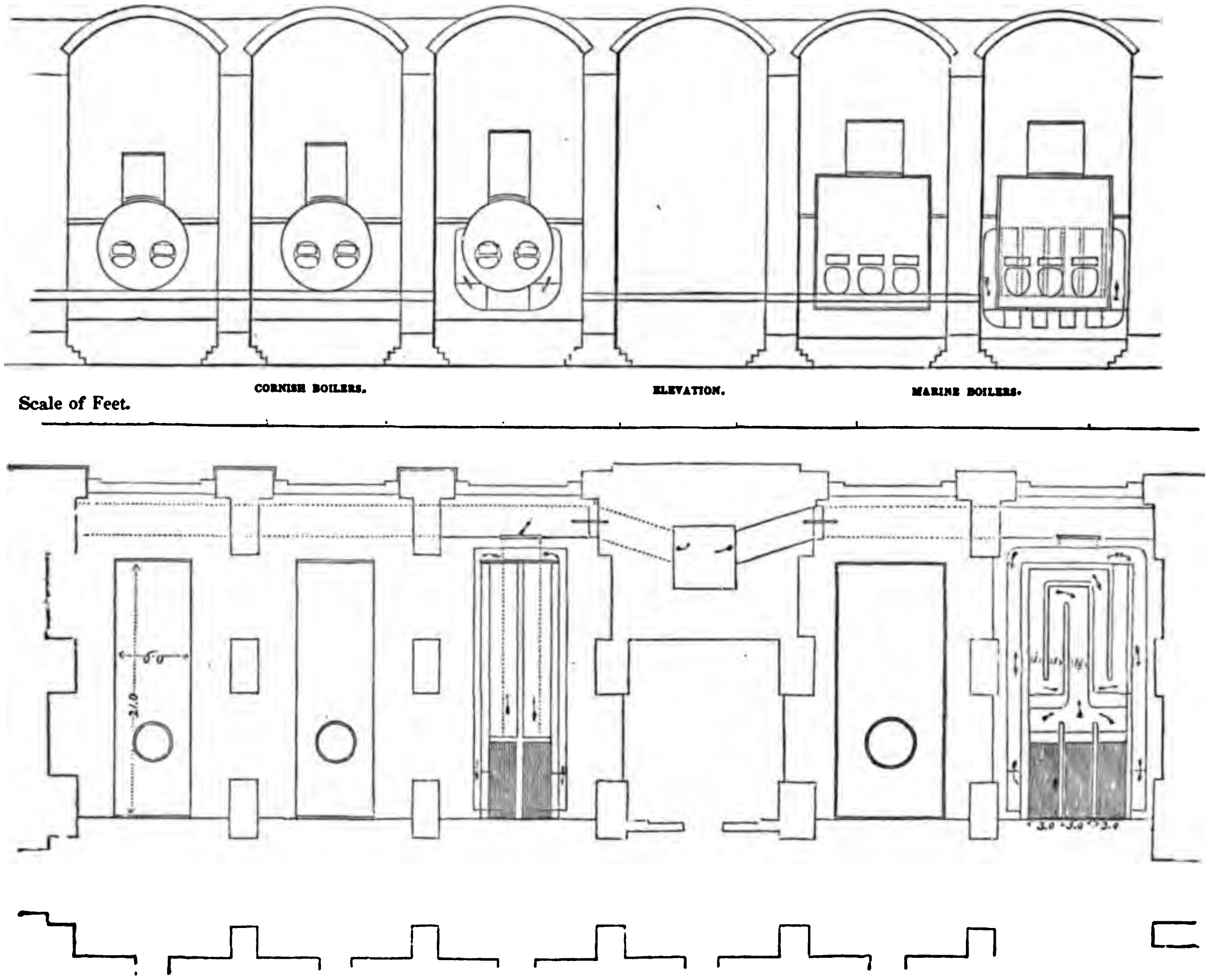
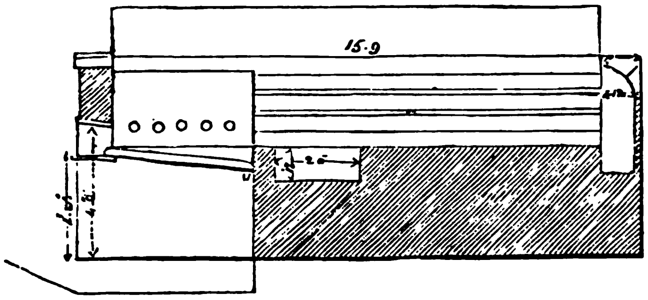


Fig. 45.



Scale one-fifth inch = 1 foot.
LAND BOILER BY MESSRS. CAIRD AND CO.
Longitudinal Section.

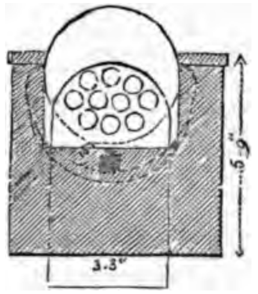
Figs. 45. and 46. represent a land boiler of a very good description constructed by Messrs. Caird and Co. for a blast engine of small size. This kind of boiler is common enough; but it has generally only one tube for conducting the smoke through the boiler, instead of the number here represented.

Figs. 47. and 48. represent the boiler introduced by Messrs. Caird into some iron tug-boats made by them. Cylinder, 32 inches in diameter, length of stroke, 3 ft. 6 inches. We shall not, in general, append the size of the engines or the number of the boilers to the drawings, as all this information will be given in a more commodious form in the tables we intend to furnish.

Figs. 49. and 50. represent a Yankee boiler, which will be looked upon as a sort of phenomenon in this country. The vessel in which this boiler is applied is said to run 150 miles in about 9 hours. The plates are $\frac{1}{4}$" thick; rivets, $\frac{9}{16}$" diameter, and the pressure of the steam is 50 lbs. !

Figs. 51, 52, 53, 54, 55, 56, are different views of the boilers of the

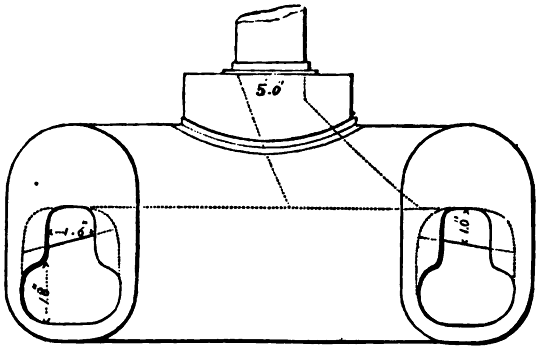
Fig. 46.



Scale one fifth inch = 1 foot.
AND BOILER BY MESSRS. CAIRD AND CO.
Transverse Section.

Phœnix, a steamer constructed by Messrs. Scott, Sinclair, and Co., for plying between Cape Town and Algoa Bay, at the Cape of Good Hope.

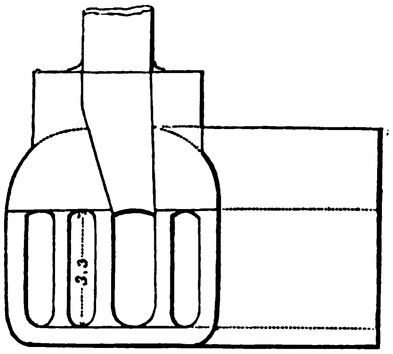
Fig. 47.



BOILER OF GREENOCK AND GLASGOW IRON TUG BOATS, BY CAIRD AND CO.
Elevation. Scale No. 2.

This vessel was provided with collecting vessels within the boiler for obviating the deposition of scale; an expedient of much efficacy, and of which at the right place we shall furnish our readers with full information.

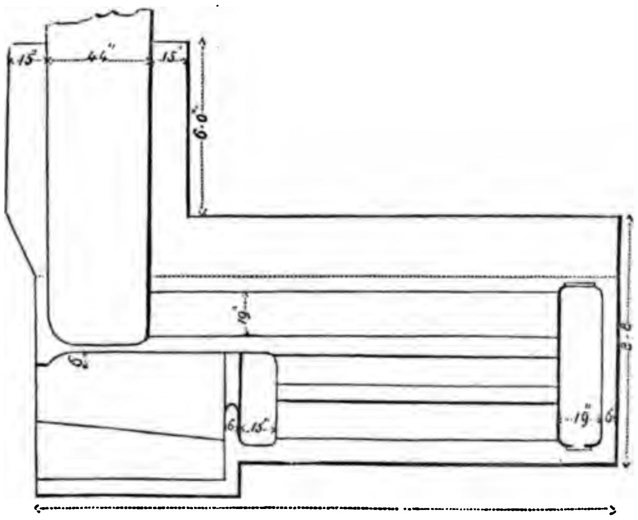
Fig. 48.



BOILER OF GREENOCK AND GLASGOW IRON TUG-BOATS, BY CAIRD AND CO.
SECTION. Scale No. 2.

Figs. 57, 58, 59, represent the boilers of the Achilles steamer, constructed by Messrs. Caird and Co. This vessel plies between Liverpool and Glasgow, and is well known for her numerous excellencies.

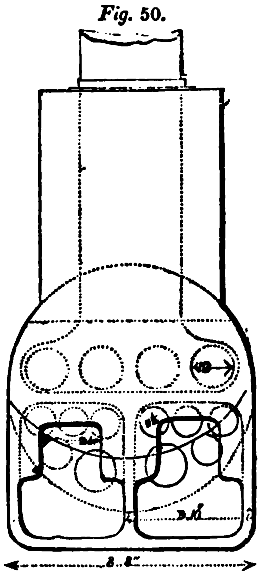
Fig. 49.



Scale three-tenth inch=2 feet.
AMERICAN BOILER.
Longitudinal Section.

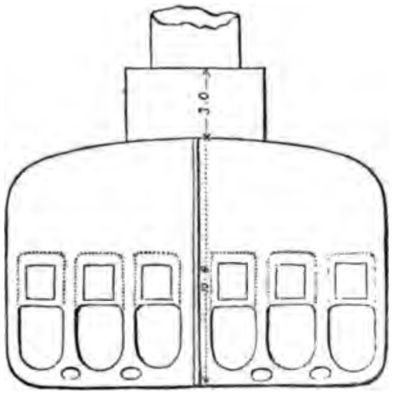
Figs. 60, 61 62. 63, and 64, are different views of the boilers of the steam vessel Don Juan, constructed by Messrs. Girdwood & Co., of Glasgow, for the Peninsular Steam Company. These boilers produced an abundance of steam for the engines, the cylinders of which were 68 inches in diameter and 6 feet in the length of stroke, but they were expensive in coal. The plan of a boiler with a double tier of furnaces seems to be more expensive in steam, apart from all considerations of convenience in firing, than boilers made with furnaces in the ordinary way. The steam rising from the under furnace will impinge on the iron of the ash-pit of the upper one,

Fig. 50.



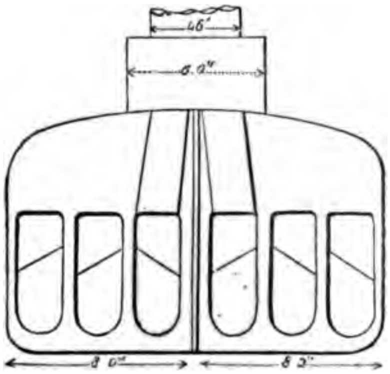
Scale three-tenth inch=2 feet.
AMERICAN BOILER.
Transverse Section

Fig. 51.



Scale one-eighth inch=foot.
BOILERS OF THE STEAMER PHŒNIX, BY MESSRS. SCOTT, SINCLAIR, AND CO.
Elevation.

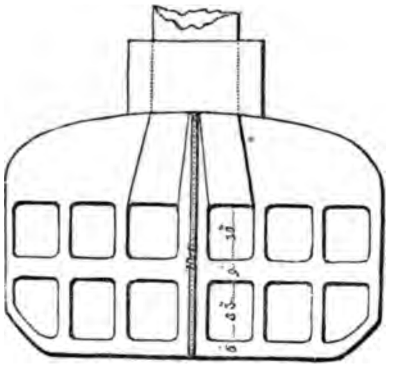
Fig. 52.



Scale one eighth inch=1 foot.
BOILERS OF THE STEAMER PHŒNIX, BY MESSRS. SCOTT, SINCLAIR, AND CO
Transverse Section.

which is kept at a low temperature by the stream of cold air rushing to the fire; and it is probable that a good deal of the steam is condensed again after it has been generated by the refrigeratory effect of the superior ash-pits.

Fig. 53.

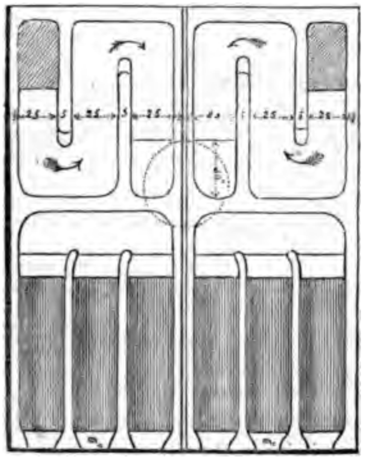


Scale one-eighth inch=1 foot.

BOILERS OF THE STEAMER PHŒNIX, BY MESSRS. SCOTT, SINCLAIR AND CO.

Transverse Section through Furnaces.

Fig. 54.

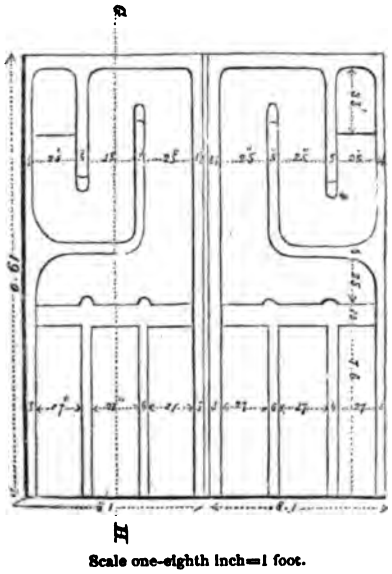


Scale one-eighth inch=1 foot.

BOILERS OF THE STEAMER PHŒNIX, BY MESSRS. SCOTT, SINCLAIR, AND CO.

Horizontal Section.

Fig. 55.

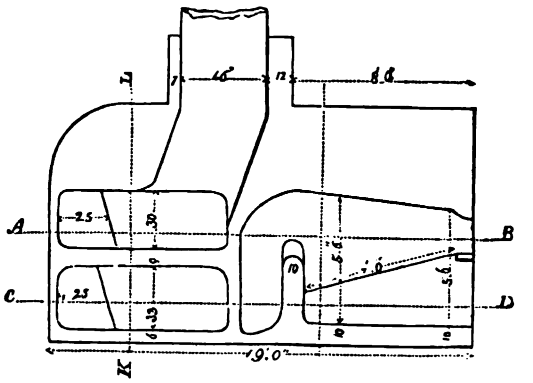


Scale one-eighth inch=1 foot.

BOILERS OF THE STEAMER PHŒNIX, BY MESSRS. SCOTT, SINCLAIR, AND CO.

Horizontal Section

Fig. 56.

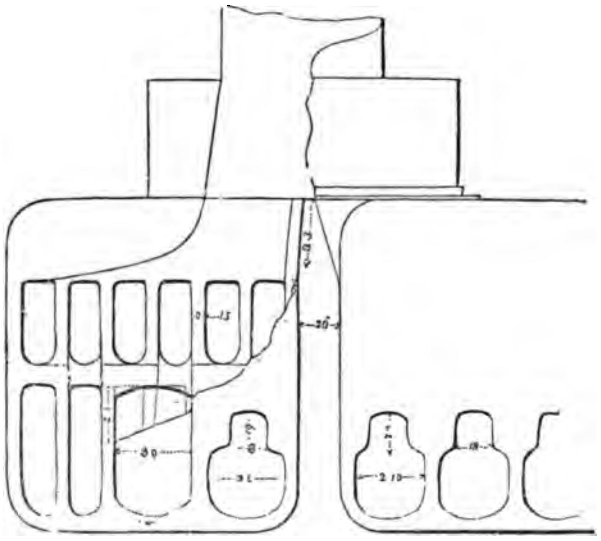


Scale one-eighth inch=1 foot.

BOILERS OF THE STEAMER PHŒNIX, BY MESSRS. SCOTT, SINCLAIR, AND CO.

Longitudinal Section.

Fig. 57.

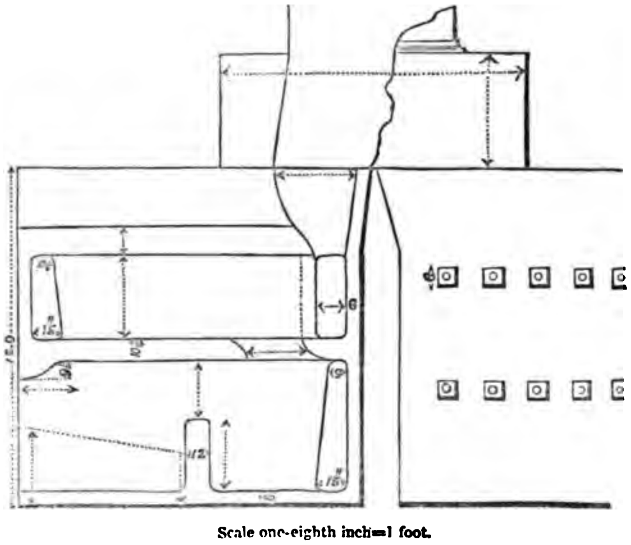


Scale one-eighth inch=1 foot.

BOILERS OF STEAMER ACHILLES, BY MESSRS. CAIRD AND CO.

Elevation and Transverse Section.

Fig. 58.

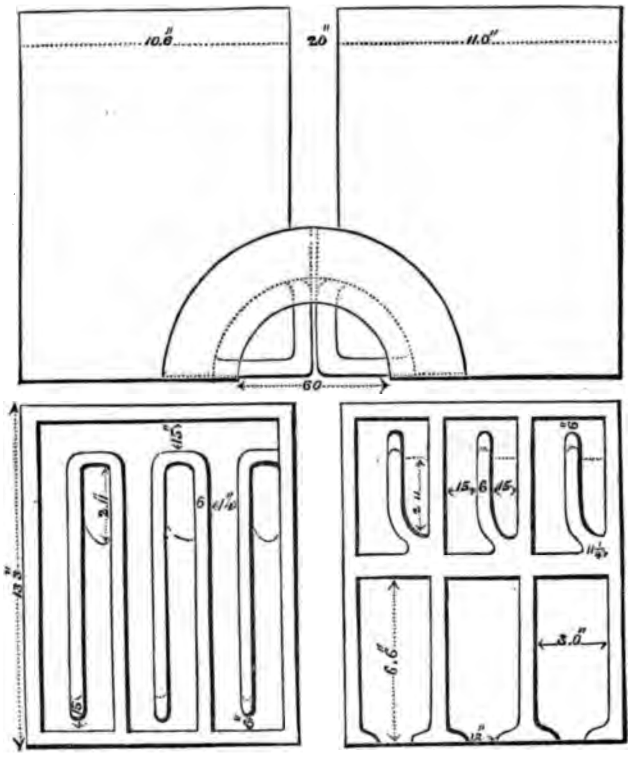


Scale one-eighth inch=1 foot.

BOILERS OF STEAMER ACHILLES, BY MESSRS. CAIRD AND CO.

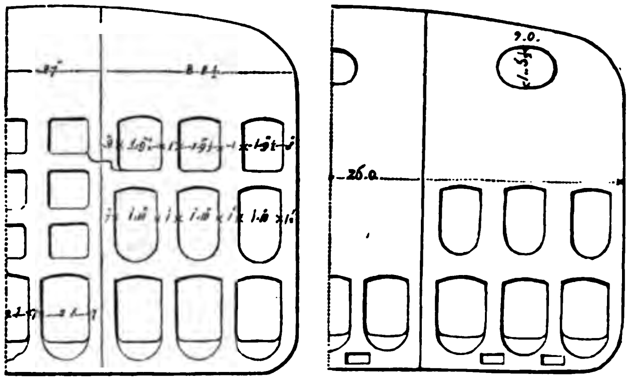
Longitudinal Section and Exterior.

Fig. 59.



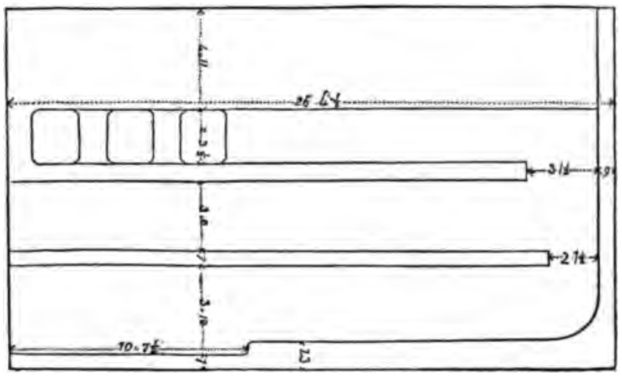
Scale one-eighth inch=1 foot.
BOILERS OF STEAMER ACHILLES, BY MESSRS. CAIRD AND CO.
Horizontal Sections and Birds'-Eye View.

Figs. 60, and 61.



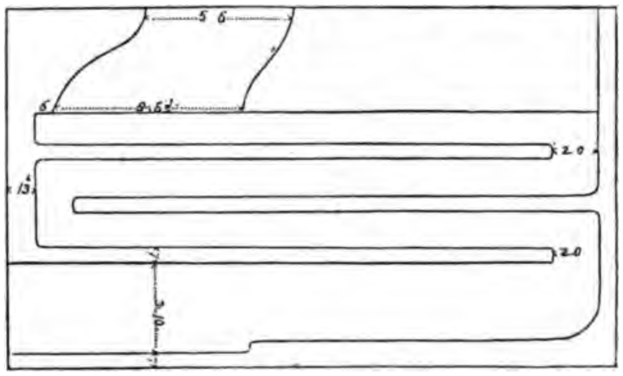
Scale one-eighth inch=1 foot.
BOILERS OF DON JUAN STEAMER, BY MESSRS. GIRDWOOD AND CO.
Transverse Section. Elevation.

Fig. 62.



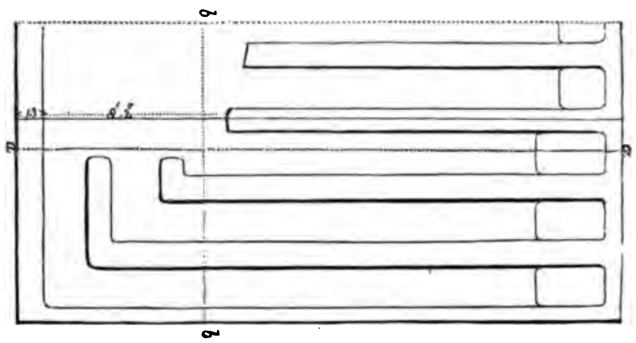
Scale one-eighth inch=1 foot.
BOILERS OF DON JUAN STEAMER.
Longitudinal Section.

Fig. 63.



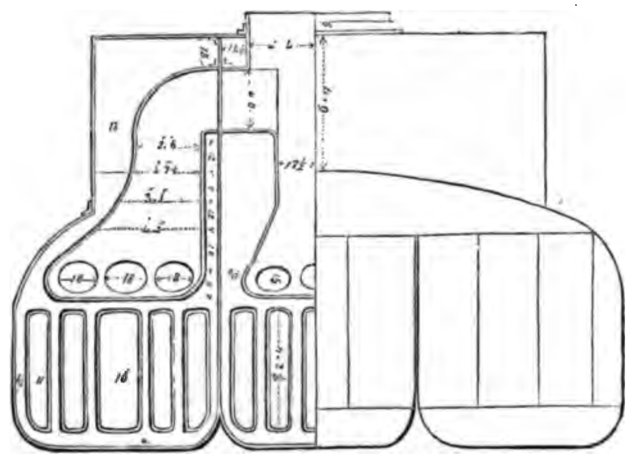
Scale one-eighth inch=1 foot.
BOILERS OF DON JUAN STEAMER.
Longitudinal Section through Chimney.

Fig. 64.



Scale one-eighth inch=1 foot.
BOILERS OF DON JUAN STEAMER THROUGH TOP FLUES.
Horizontal Section.

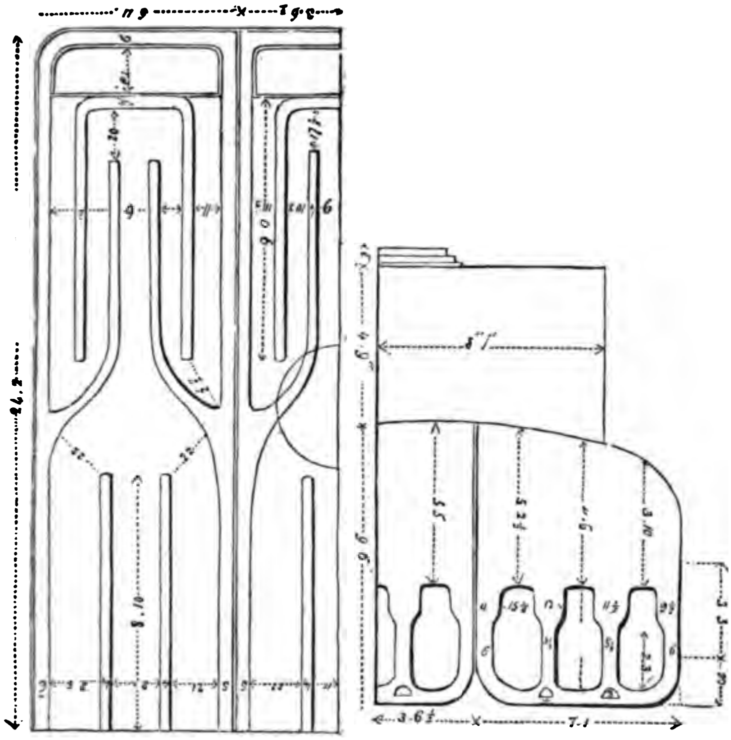
Fig. 65.



Scale three-tenth inch=2 feet.
BOILERS OF UNICORN STEAMER.
Transverse Section and End View.

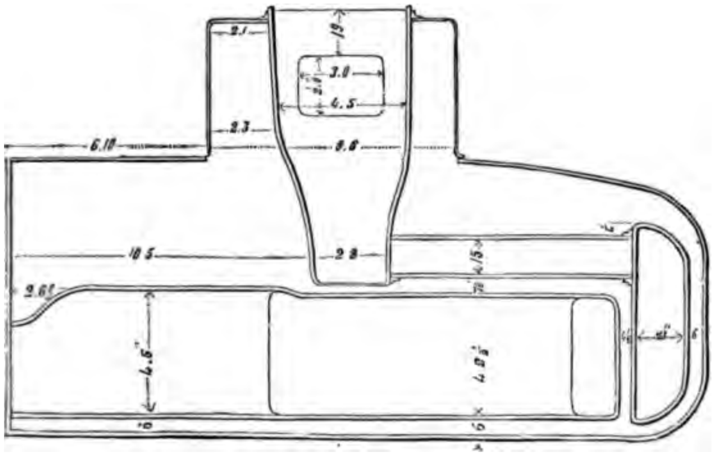
Figs. 65, 66, 67, and 68. are delineations of the boilers of the Unicorn steamer by Messrs. Caird and Co.; and *figs.* 69. and 70. represent the boilers of the sister ship, the Eagle, also by the same makers. There is nothing of peculiar excellence in these plans; and, for steam vessels, we believe boilers of this kind will be superseded by the tubular plan of boiler, of which we shall give all the best specimens. But a good number of boilers upon the common flue plan are still made, so that some specimens of them are indispensable; and, indeed, there are still far more flue boilers in use than there are of any other description. In most of these boilers it is a fault that the furnaces are made too long and narrow, and the consequence is, that it is impossible to fire them on a long sea-voyage, especially in stormy weather. It is much preferable to restrict the furnaces to a moderate length, and give the bars a considerable elevation, so that they always be well covered with coal at the after ends. When the furnaces are very long, a good deal of air generally escapes into the flues at the after end of the bars, the effect of which is materially to lessen the generation of steam.

Fig. 66. *Fig.* 67.



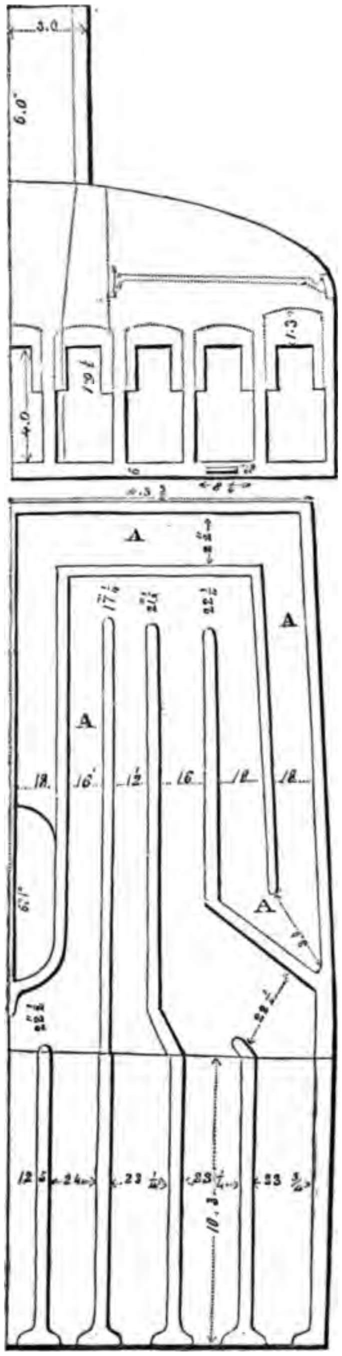
Scale three-tenth inch = 2 feet.
BOILERS OF THE UNICORN STEAMER, BY MESSRS. CAIRD AND CO.
Horizontal Section. Elevation.

Fig. 68.



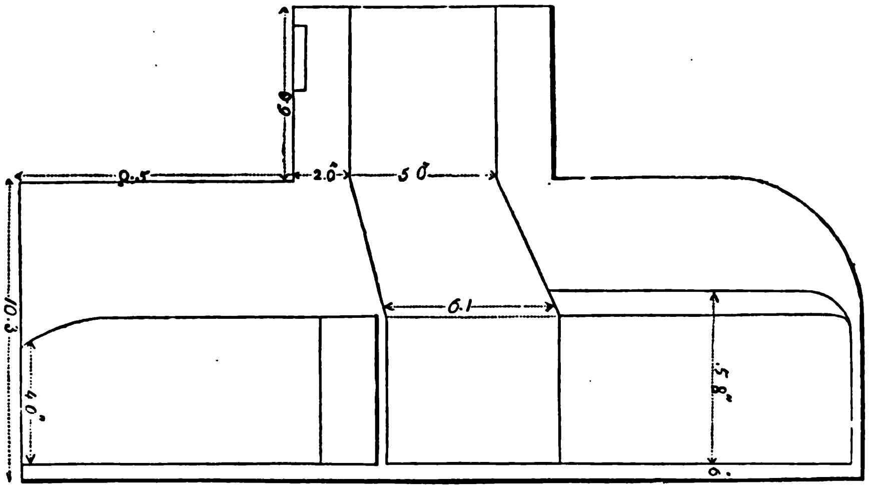
Scale three-tenth inch = 2 feet.
BOILERS OF UNICORN STEAMER.
Longitudinal Section.

Fig. 69.



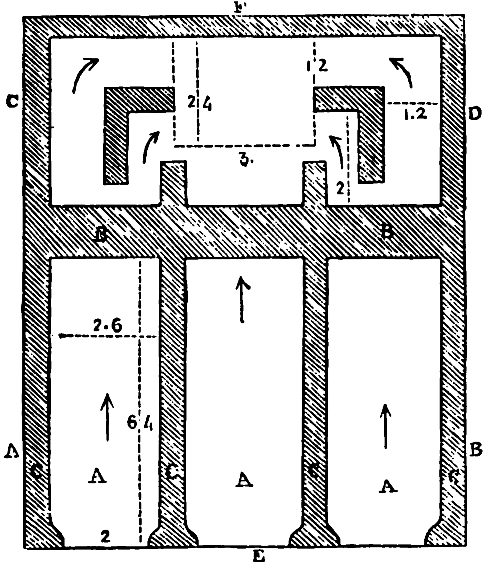
Scale three-tenth inch = 2 feet.
BOILERS OF STEAMER EAGLE, BY MESSRS. CAIRD AND CO.
Elevation and Horizontal Section.

Fig. 70.



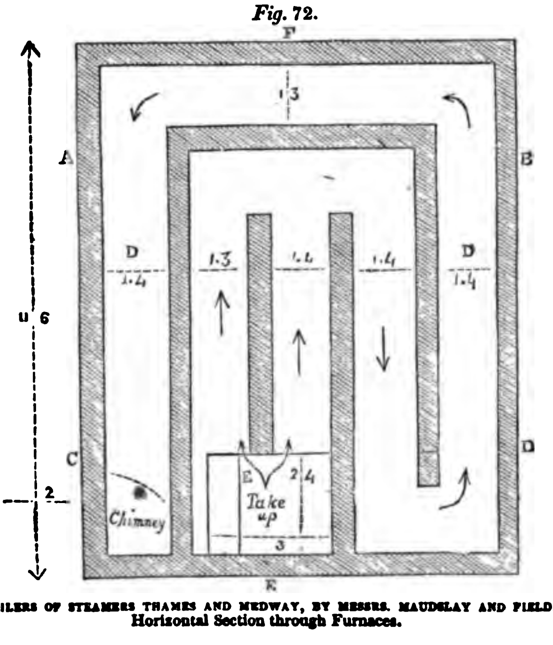
BOILER OF STEAMER EAGLE, BY MESSRS. CAIRD AND CO. Longitudinal Section.

Fig. 71.



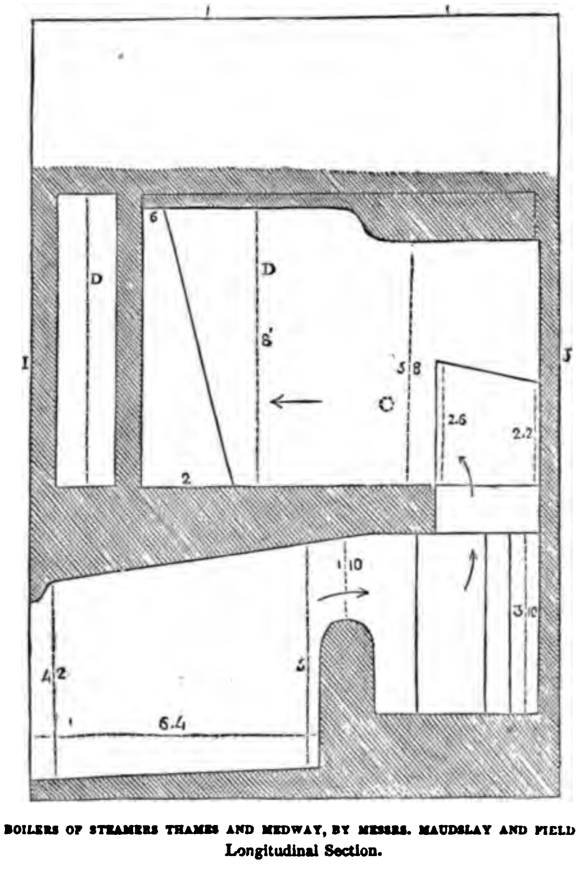
BOILERS OF STEAMERS THAMES AND MEDWAY, BY MESSRS. MAUDSLAY AND FIELD. Horizontal Section through Flues.

Fig. 72.



BOILERS OF STEAMERS THAMES AND MEDWAY, BY MESSRS. MAUDSLAY AND FIELD. Horizontal Section through Furnaces.

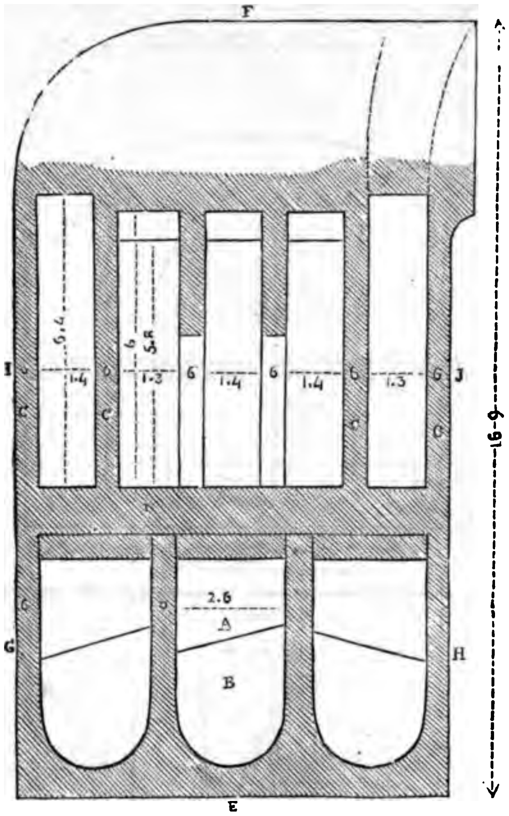
Fig. 73.



BOILERS OF STEAMERS THAMES AND MEDWAY, BY MESSRS. MAUDSLAY AND FIELD. Longitudinal Section.

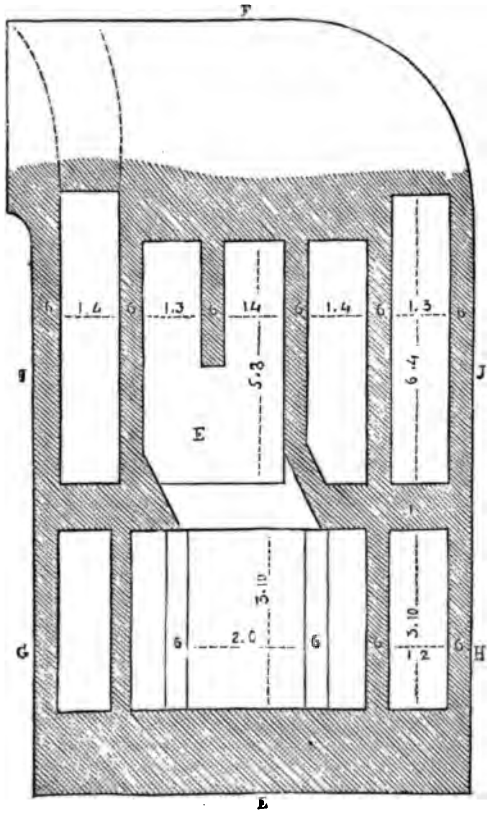
Figs. 71, 72, and 73 represent the boilers of the Thames and Medway, two vessels of large size, constructed by Messrs. Maudslay and Field for the Royal Mail Steam Packet Company. The boilers of these vessels have been very successful, and are among the best specimens of the flue boiler as applicable to marine engines hitherto produced. We do not know of any boiler of this kind that engineers may imitate with greater safety, as regards their power of generating steam, though there are many specimens distinguished by a greater durability. In some of the boilers recently introduced in the Royal Mail Steamers, the furnaces stand athwartships, and the plan is attended with the material advantage that the coals trim more easily; for the coal reserve in this arrangement situated behind the boilers, and another depôt standing between the boilers and the engines, communicate immediately with the stoke-holes, whereby an easy transfer of the coal becomes accomplishable.

Fig. 74.



Scale one quarter inch=1 foot.
BOILERS OF STEAMERS, THAMES AND MEDWAY, BY MESSRS. MAUDSLAY, SONS, AND FIELD.
Section through AB.

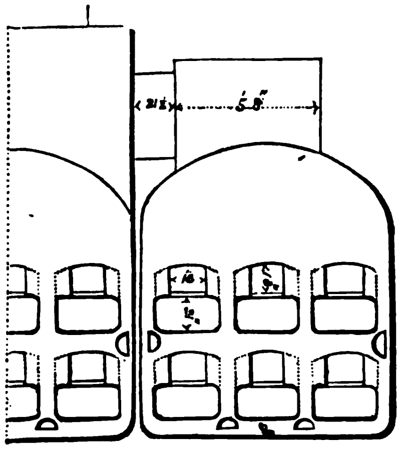
Fig. 75.



Scale one quarter inch=1 foot.
BOILERS OF STEAMERS, THAMES AND MEDWAY, BY MESSRS. MAUDSLAY, SONS, AND FIELD.
Section through CD.

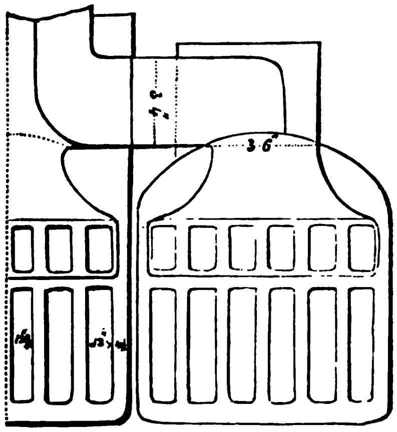
Figs. 74. and 75. are also views of the boilers of the Thames and Medway. These views are perpendicular sections through the lines A B and C D, shown in the horizontal section through the furnaces, *fig.* 71., and the horizontal section through the flues, *fig.* 72. The dotted sweeps at the two upper corners represent the ascent of the flue into the funnel. The flue narrows in width and rises in height as it approaches the chimney, for the same area is not required for the transmission of the smoke after its volume has been contracted by the communication of heat to the water, and a less depth of water above the flue suffices after the heat of the smoke traversing it has been well nigh expended. The bridges B (*fig.* 74.) are water bridges, and their superior ridges do not run in a horizontal, but in an oblique direction, the design of which is to facilitate the extrication of the steam. There are four boilers in all, and the boilers are fired from both ends.

Fig. 76.



Scale one and half tenth inch=1 foot.
BOILERS OF THE STEAMERS, DEE AND SOLWAY, BY MESSRS. SCOTT, SINCLAIR, AND CO.
Elevation.

Fig. 77.

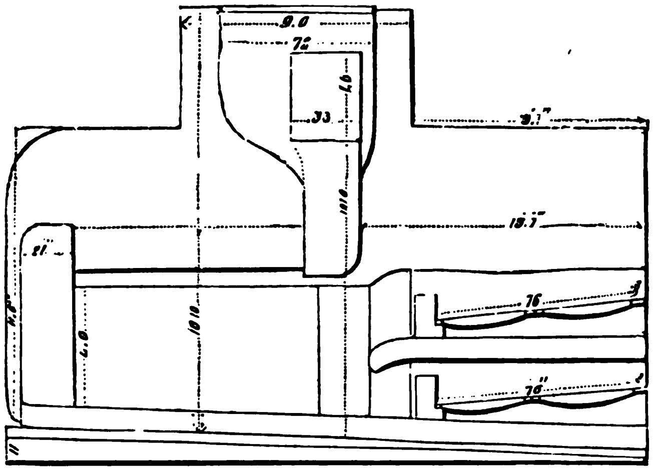


Scale one and half tenth inch=1 foot.
BOILERS OF STEAMERS, DEE AND SOLWAY, BY MESSRS. SCOTT, SINCLAIR, AND CO.
Transverse Section.

Figs. 76, 77, 78, and 79., represent the boilers of the steamers Dee and Solway, constructed for the Royal Mail Steam Packet Company by Messrs. Scott, Sinclair, and Co., of Greenock. These boilers, it will be remarked, have a double tier of furnaces one above the other, instead of being fired from both ends as in the preceding example. The length of the aftermost firing space is saved to the vessel by this arrangement, but the plan has disadvantages enough to overweigh this benefit. Of these, the chief perhaps is, that it is very difficult to fire the two tiers of furnaces effectually. The coals, moreover, do not lead from the coal boxes so conveniently, or so well maintain the trim of the ship, as when the boilers are fired from both ends. It appears to us, moreover, that the steam rising from the lower tier of furnaces must be cooled and weakened by its impact against the ashpit bottoms of the upper tier, into which a stream of cold air is always passing to maintain the combustion of the fires. The ashpits, are necessarily inconveniently shallow, and, as will be remarked by referring to *fig.* 78., it becomes difficult with such shallow ashpits to obtain the necessary inclination for the furnace bars. These considerations indispose us to this description of boiler, and indeed it is fast falling into disuse.

There are three boilers in each vessel, with six furnaces in each boiler, making eighteen furnaces in each vessel. The boilers represented are properly those of the Solway, for those of the Dee, instead of being each rounded on the top in the manner shown in the drawing, have the top carried in one sweep from the one side of the boiler to the other, so that the tops of the several boilers form conjointly part of an ellipse. The total heating surface of these boilers is 4156 square feet; total fire surface 46850·4 square inches; weight of each boiler 27½ tons; the diameter of the cylinders of these vessels is 73 inches; length of stroke 7 feet; nominal horse power 400; heating surface per horse power 10·3 square feet; fire surface per horse power 117 square inches.

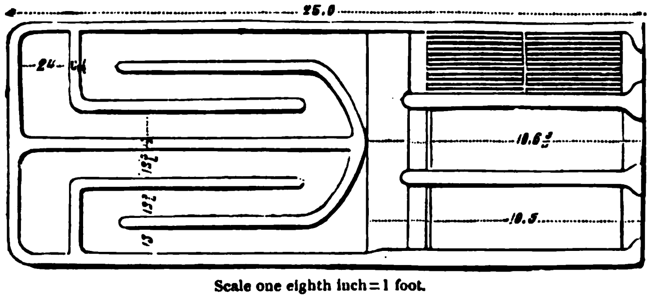
Fig. 78.



Scale one eighth inch=1 foot.
BOILERS OF STEAMERS, DEE AND SOLWAY, BY MESSRS. SCOTT, SINCLAIR, AND CO.
Longitudinal Section.

In furnaces with two lengths of furnace bars, it is a good plan to make the centre bearer double, so that the ends of the bars may have a space between them through which the ashes will be precipitated; the space thus left enables the bars to expand without injury on the application of heat, whereas, without some such provision, the bars are very liable to get burned out by their centres bending up into the furnace, or else the lugs which carry the bearer bars will be perpetually being carried away. A similar space should be left between the fore end of the bars and the dead plate at the furnace mouth, and care should be taken that not only the ends of the bars do not touch, but that the heels of the bars do not rest against the furnace bearers.

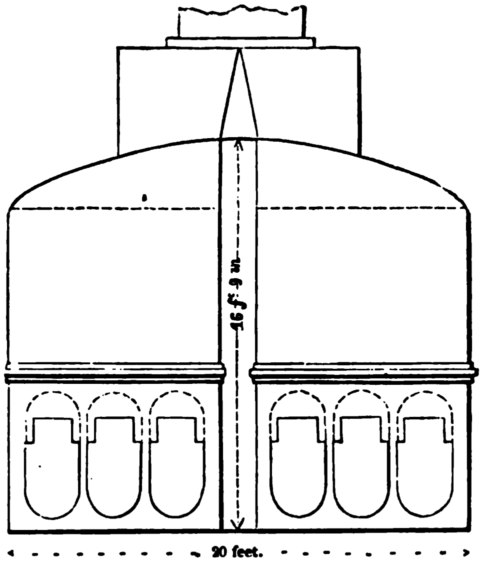
Fig. 79.



Scale one eighth inch=1 foot.
BOILERS OF STEAMERS, DEE AND SOLWAY, BY MESSRS. SCOTT, SINCLAIR, AND CO.
Horizontal Section.

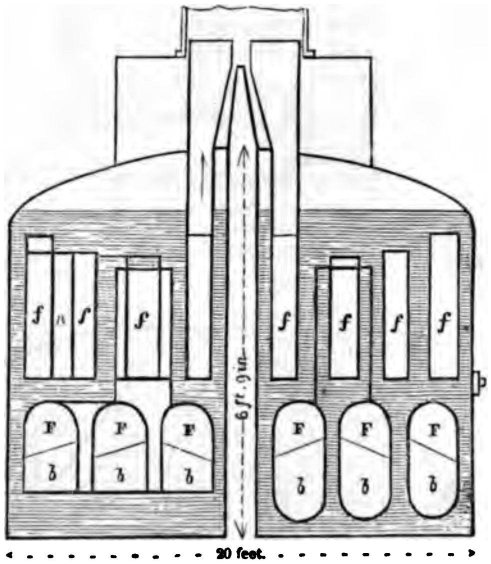
The bridges of these boilers are, it will be observed, of brick, and come tolerably close to the furnace top. In such cases it is expedient to make the upper part of the bridge consist of one or two fire brick blocks which may be lifted off when a person requires to enter the flues to sweep or repair them. The continual knocking down and building up of bridges becomes otherwise very expensive. In boilers of this construction it is difficult to light one tier of fires after the others have been thoroughly kindled, as the fires first lighted keep the lead in the draught. It might be anticipated that by firing the tiers of fires alternately, the smoke would be burned, but such is not found to be the effect.

Fig. 80.



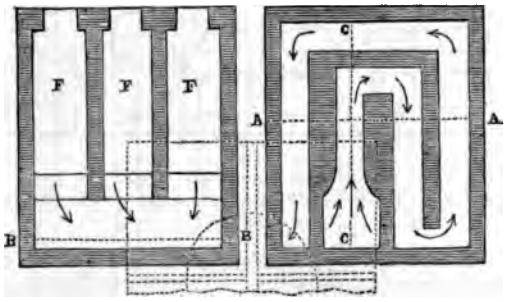
Scale one-eighth inch=1 foot.
ORIGINAL BOILERS OF GREAT WESTERN STEAMER, BY MESSRS. MAUDSLAY, SONS, AND FIELD.
Elevation.

Figs. 81, 82.



Scale one-eighth inch=1 foot.
ORIGINAL BOILERS OF GREAT WESTERN STEAMER, BY MESSRS. MAUDSLAY, SONS, AND FIELD.
Section through B. Section through A.

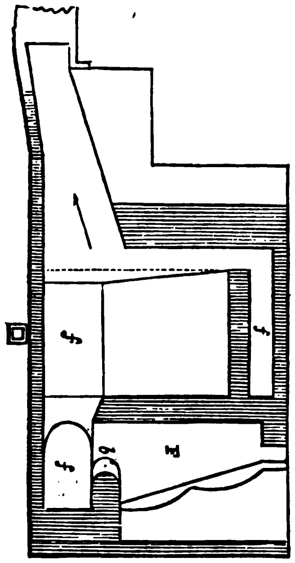
Figs. 83, 84.



Scale one-eighth inch=1 foot.
ORIGINAL BOILERS OF GREAT WESTERN STEAMER, BY MESSRS. MAUDSLAY, SONS, AND FIELD
Section through Furnaces F. Section through Flues *f*.

Figs. 80, 81, 82, 83, 84, 85. represent the original boilers of the Great Western steamer as made by Messrs. Maudslay, Sons, and Field, and *figs.* 86. 88, 89, and 90. the present boilers of the same vessel, which are of the tubular description. These tubular boilers are rather short of steam, the fault being that the tubes extract the heat from the smoke too effectually, and leave but little waste heat to maintain the draught: but this evil may easily be remedied, either by putting a steam blast pipe into the chimney, as in the case of locomotives, or by cutting a hole through the water-space that separates the inferior and superior smoke boxes at the after end of the boiler, so that some of the smoke will ascend the chimney without passing through the tubes at all. These perforations might be fitted with dampers, so as just to allow enough hot air to escape through them to maintain the draught, and no more.

Fig. 85.

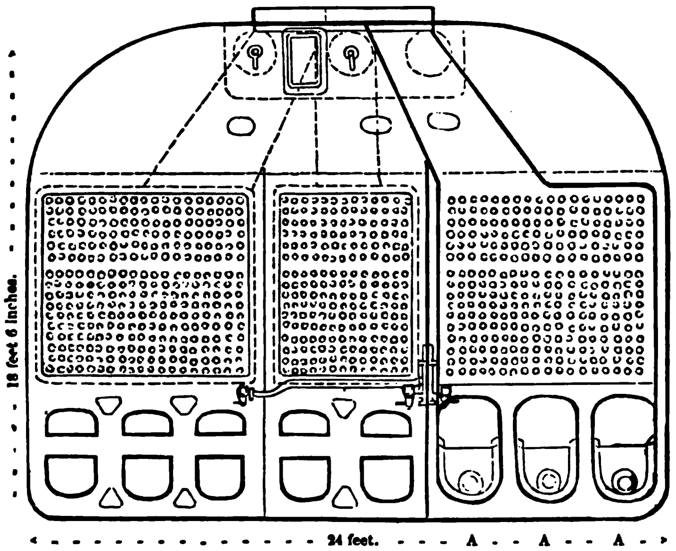


Scale one-eighth inch=1 foot.

ORIGINAL BOILERS OF GREAT WESTERN STEAMER, BY MESSRS. MAUDSLAY, SONS, AND FIELD.

Perpendicular Section through C.

Fig. 86.



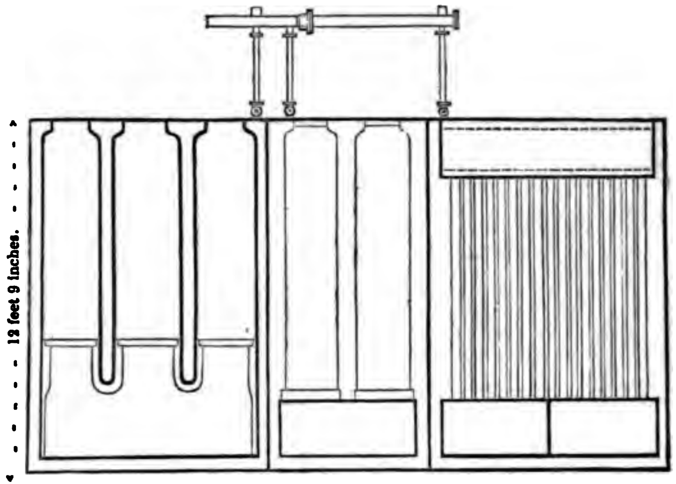
Scale nine sixty-fourth inch=1 foot.

PRESENT BOILERS OF THE GREAT WESTERN STEAMER, BY GREAT WESTERN STEAM CO., 1844.

Transverse Section.

Provision has been made in these boilers for the introduction of a fan blast, which would at once cure the evil of a defective draft. The furnaces would, in this plan, be made close, and the blast would be introduced into a chamber at the back of the ashpit A., *fig.* 90., from whence it would pass into the ashpits by necks A A A, *fig.* 86. One inconvenience, however, of a fan blast thus applied is, that the smoke comes out of the furnace doors very much when they are opened.

Figs. 87, 88, 89.



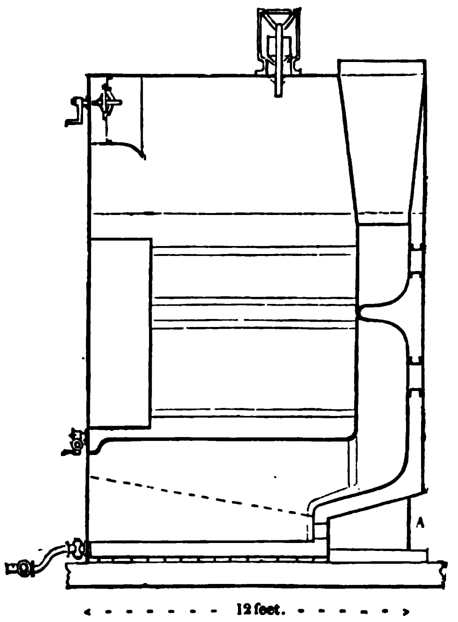
Scale nine sixty-fourth inch=1 foot.

PRESENT BOILERS OF GREAT WESTERN STEAMER, BY GREAT WESTERN STEAM CO., 1844.

Horizontal Section through Furnaces. Horizontal Section above Furnaces. Horizontal Section above Tubes.

The particulars respecting the scarcity of steam in these boilers we have obtained from Mr. Guppy, by whom we believe the boilers were designed. Almost every engineer has made tubular boilers that were short of steam, but we never before met with one who acknowledged it.

Fig. 90.



Scale nine sixty fourth inch=1 foot.

PRESENT BOILERS OF THE GREAT WESTERN STEAMER, BY GREAT WESTERN STEAM CO., 1844

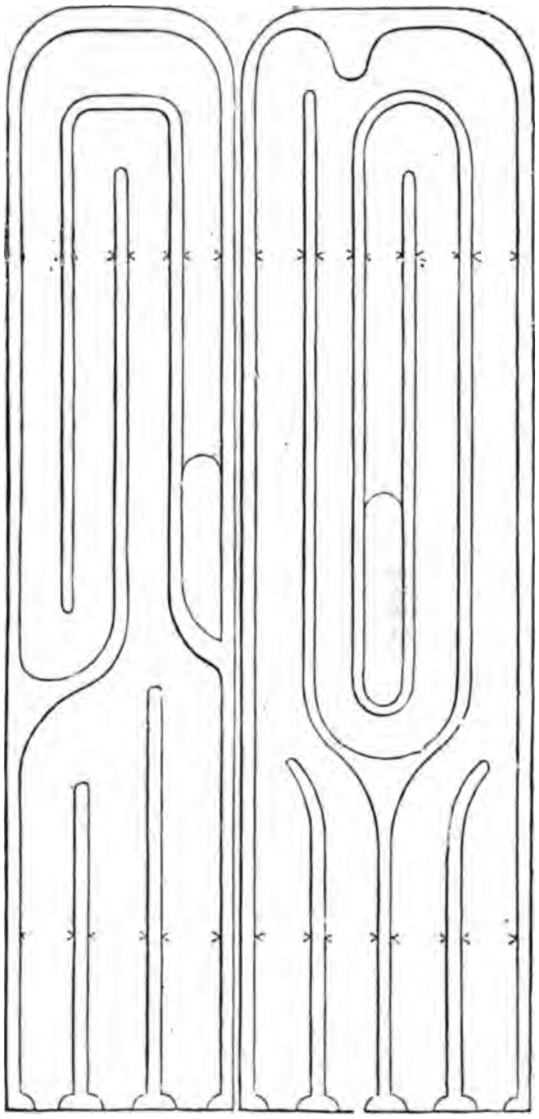
Longitudinal Section.

The original boilers of the Great Western, as represented in *figs.* 80. to 85., contained of flue surface 2950 square feet, and of furnace surface 890 square feet, making 3840 square feet of heating surface; area of fire grate 202 square feet: capacity of steam room 1150 cubic feet; weight of boilers and steam pipes 202 tons; weight of water 80 tons; average consumption of coal 1000 tons per voyage out and home of 27 or 28 days. In the tubular boilers, *figs.* 86. to 90., the tube surface is 5900 square feet, smoke box surface 830 square feet; furnaces 420 square feet; making 7150 square feet of heating surface; area of fire grate 145 square feet; weight of boilers 56 tons; weight of water 52 tons; capacity of steam room 1320 cubic feet; average consumption of coal per voyage out and home of 29 days 696 tons. The speed of the vessel, it will be observed, has somewhat declined with the new boilers, but there is a greater economy in fuel upon the same distance. The horse power of the Great Western is about 400; the particulars of the two boilers will therefore stand as follows:—

	Old Boiler.	New Boiler.
Heating surface per horse power	9·6	17·875
Fire-grate per horse power	·5	·3625
Steam room per horse power	2·875	3·3
Coal per hour per horse power	8·333	5·6

The consumption of fuel, as here set down, it must be borne in mind, is that of the old boiler in its superannuated state, and of the new boiler in its best state. The old boiler when new did not consume more than 6 lbs. of coal per horse power per hour.

Fig. 91.

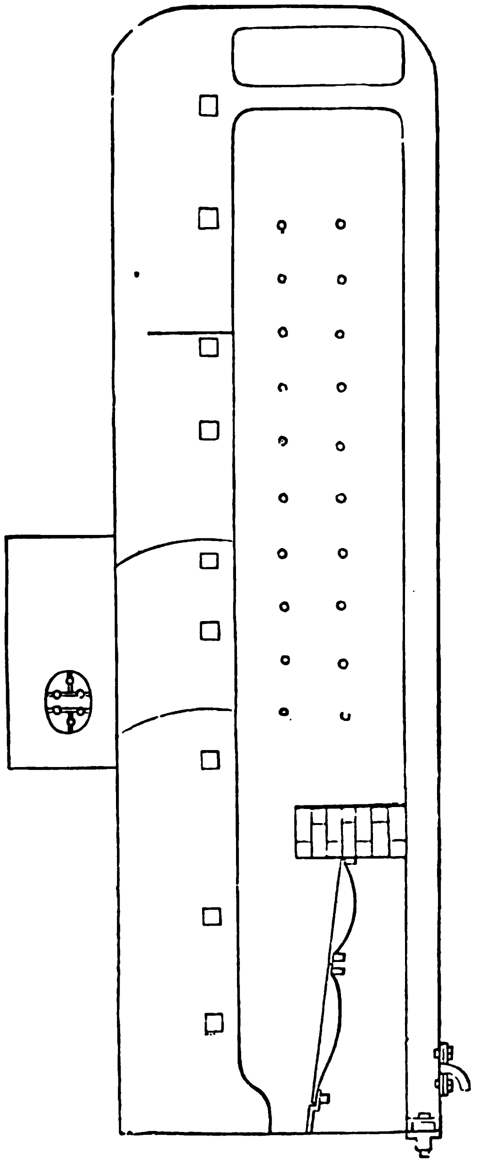


BOILERS OF BRITISH QUEEN STEAMER, BY R. NAPIER, GLASGOW.
Horizontal Section.

The tubes of these tubular boilers are of iron of 3 inches internal diameter, and 8 feet in length. The furnaces the 8 feet 3 inches in length, which is in our judgment a greater length than can be fired effectually on so long a voyage as the Great Western has to perform. The water within the boiler rises some distance above the top tubes: it would be better, we think, to let the return tubes go through the steam, which would dry it very effectually, and surcharge it in some degree with heat. This could easily be done by lowering the water level, and the hot air will be sufficiently cooled after passing through the lower tier of tubes, to prevent any injury to the upper tier from an excess of heat. One of the advantages of iron tubes, is, that they can be subjected to a degree of heat with impunity that would be unsafe to apply in the case of brass tubes. It is said, however, that the scale adheres to them with greater tenacity than to brass, but this objection is not likely to prove of much weight if the boilers be well blown out, for, in that case, very little scale will be formed at all.

Figs. 91. and 92. represent the boilers of the British Queen steamer, constructed to ply between London and New York. There is nothing very peculiar in this kind of boiler, and indeed it is nothing more than the common marine boiler as used for the ordinary coasting vessels constructed upon a larger scale. There are four boilers in the vessel ranging athwartships, containing in all fourteen furnaces, the wing boilers containing four furnaces each, and the midship boilers three furnaces each. The projection of the water-space into the flues at the after-end of the wing boiler is to obviate a back-draft in the furnaces, in consequence of the currents of hot air meeting one another in a direct antagonism at the point where they coalesce, and which they would do but for this protuberance, which deflects each of them sufficiently to make it enter, without conflict, the longitudinal flue. These boilers were kept supplied with fresh water, as the engines are fitted with Hall's condensers, which return the condensed steam to the boiler to maintain the water level. This species of condenser is now discontinued in most vessels, as its weight and expense are formidable objections, and it does not act as a preservative of the iron of the boiler from corrosion. One government vessel some time since fitted with Hall's condenser had no less than 22 miles of copper pipe for accomplishing the condensation of the steam. The use of salt water in boilers is attended with very little inconvenience, if they be often blown out, and their durability is little if at all increased by the employment of fresh water.

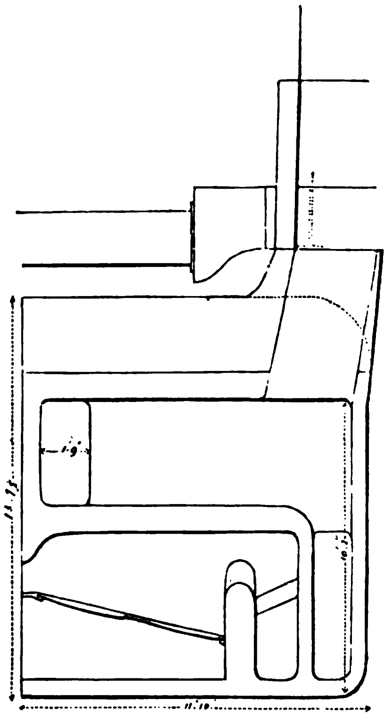
Fig. 92.



BOILERS OF BRITISH QUEEN STEAMER, BY R. NAPIER, GLASGOW.
Longitudinal Section.

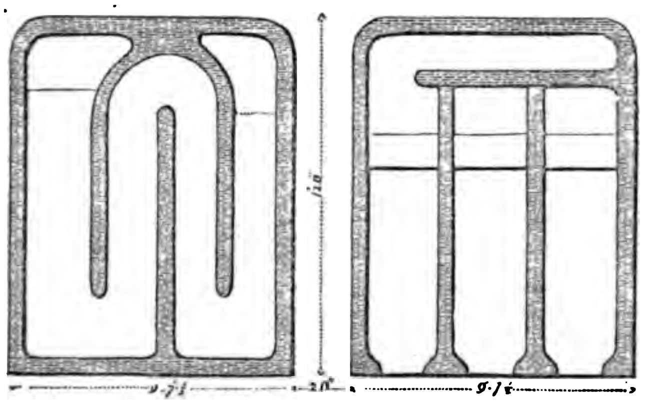
Figs. 93, 94, and 95, represent the boilers of the City of London, steamer, a vessel lately constructed by Mr. Napier of Glasgow, to ply between Aberdeen and London. These boilers are much upon the plan of the boilers of the Thames and Medway, and are fired from both ends instead of from one end, as in the boilers of the British Queen. There is a hanging water bridge, it will be observed, at the end of the furnace, (*fig.* 93.) beneath which the flame has to descend before it can enter the flues. This arrangement we look upon as very judicious. The hot air, by virtue of its specific levity, ascends into the upper part of the furnace-chamber, where it remains until it has given out a considerable portion of its heat, and it is only after its specific gravity has been increased by the extraction of heat that it can overflow into the flues. It is also a good practice to place a hanging bridge of sheet iron at the after end of the flue, where it enters the chimney.

Fig. 93.



Scale one and half tenth inch=1 foot.
BOILERS OF THE CITY OF LONDON STEAMER, BY R. NAPIER, GLASGOW, 1844.
Perpendicular Section.

Figs. 94, 95.



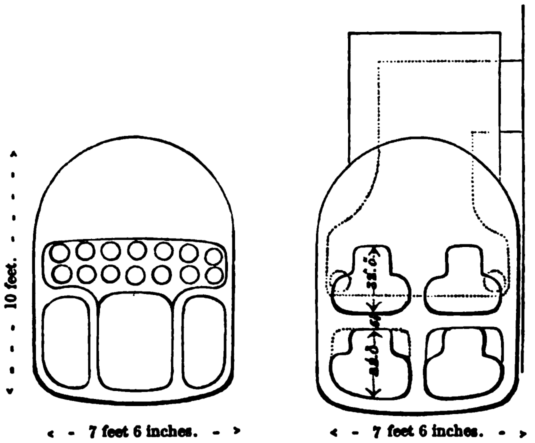
Scale one and half tenth inch=1 foot.
BOILERS OF CITY OF LONDON STEAMER, BY R. NAPIER, GLASGOW, 1844.
Horizontal Section.
Through Flues. Through furnaces.

Plate XXXI represents the boilers of the Sydenham, and is a common type of boilers made at the Government yard at Woolwich.

Plate XXXII represents the boilers of the Braganza, a vessel with 62 inch cylinders, and 5·6 inches stroke. These boilers which are by Messrs. Bury, Curtis, and Kennedy, have been found very satisfactory and successful.

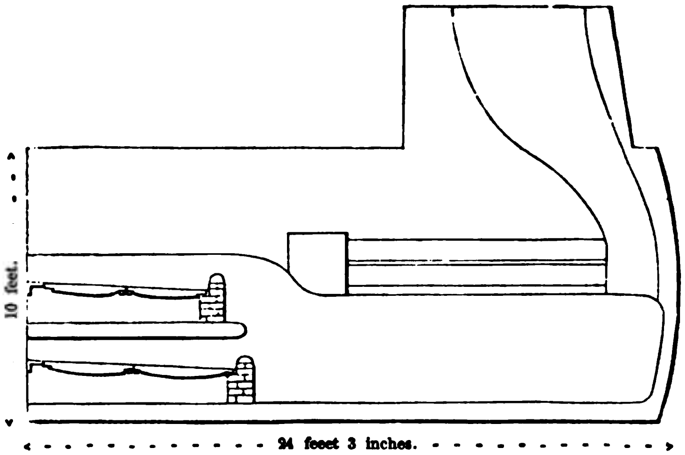
Figs. 96, 97, and 98, represent the original boilers of the steamer Tagus, constructed by Messrs. Scott, Sinclair, & Co.; and *figs.* 99, 100, and 101, the present boilers of the same vessel, which are of the tubular description, made by Messrs. Miller, Ravenhill, & Co. The following are some of the dimensions of the original boilers:—Length 24 feet 3 inches, height 10 feet; breadth of each boiler 7 feet 6 inches, making the total breadth of the boilers about 22 feet 8 inches, with projections of rivet heads. Length of under furnaces 8 feet; length of upper furnaces 7 feet 6 inches. Breadth of furnaces 3 feet; total number of furnaces 12. Each boiler contains fourteen iron pipes of about 10 inches in diameter, and 10 feet in length, through which the smoke passes on its way to the chimney. These pipes are formed of boiler plate, with turned rings or collars attached to each end, which are inserted into holes in the smoke-box plates, and then riveted over. These rivets are liable to get burned away by the action of the flame, as the collars within prevent the water from getting access to the angle, and the plates into which they are fixed then get pressed out by the force of the steam. It would be a good plan to cover these rivets with

Fig. 96.



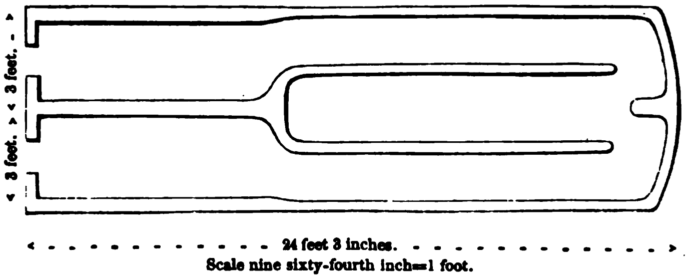
Scale nine sixty-fourths inch=1 foot.
ORIGINAL BOILERS OF STEAMER TAGUS, BY MESSRS. SCOTT, SINCLAIR, AND CO., 1838.
Transverse Section. Elevation.

Fig. 97.


10 feet.
< - - - - - - - - - - - - 24 feet 3 inches. - - - - - - - - - - - - >

Scale nine sixty-fourths inch=1 foot.
ORIGINAL BOILERS OF STEAMER TAGUS, BY MESSRS. SCOTT, SINCLAIR, AND CO., 1838.
Longitudinal Section.

Fig. 98.

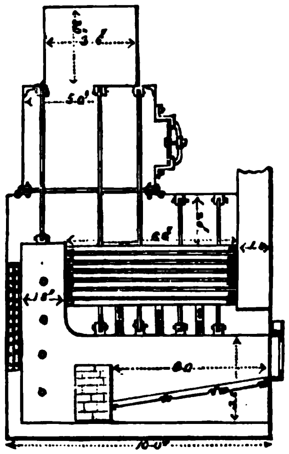

3 feet.
3 feet.
< - - - - - - - - - - - - 24 feet 3 inches. - - - - - - - - - - - - >

Scale nine sixty-fourth inch=1 foot.
ORIGINAL BOILERS OF STEAMER TAGUS, BY MESSRS. SCOTT, SINCLAIR, AND CO., 1838.
Horizontal Section.

another perforated plate placed above them, the holes in which should be of a somewhat smaller diameter than that of the tubes.

The present boilers of the Tagus we cannot regard as Messrs. Miller and Ravenhill's most successful specimen of tubular boilers, for they are liable to prime, and the water-level, in consequence of the elevated position of the tubes in the crown of the boiler, is liable to sudden and large fluctuations. These boilers are fired from each end, as in the cases of several of the boilers we have already described, and there are four boilers in all to supply the engines with steam. The cylinders are 62 inches in diameter, and the length of the stroke 5 feet 9 inches. The boilers are 10 feet long each, making the length 20 feet when placed back to back, or with a passage between the ends, and measuring over the furnace-mouths about 23 feet, as in the case of the former boilers. The width across the boiler, at the widest part, is about 7 feet, and there is a passage between the boilers, making the total width of the boilers about 15 feet. The height is 9 feet, but the whole of the space above the top of the boiler is occupied with funnels, pipes, and steam chests, whereas in the former plan coal was carried above the boiler. The saving in width is therefore nearly made up by a loss of space in the direction of the height, and then there is the extra room occupied by the after firing space, so that, although these boilers are small, they in reality accomplish little or no saving of capacity in the ship. They are considerably lighter than the old boiler, however, which is an advantage.

Fig. 99.



Scale nine sixty-fourths inch=1 foot.

PRESENT BOILERS OF THE STEAMER TAGUS, BY MESSRS. MILLER, RAVENHILL, AND CO., 1844.

Perpendicular Section.

Fig. 100.

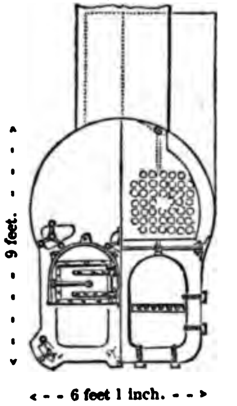
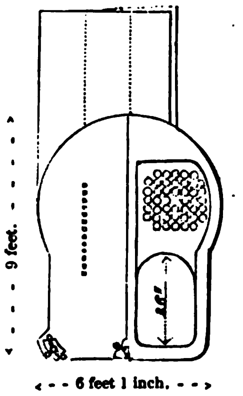


Fig. 101.



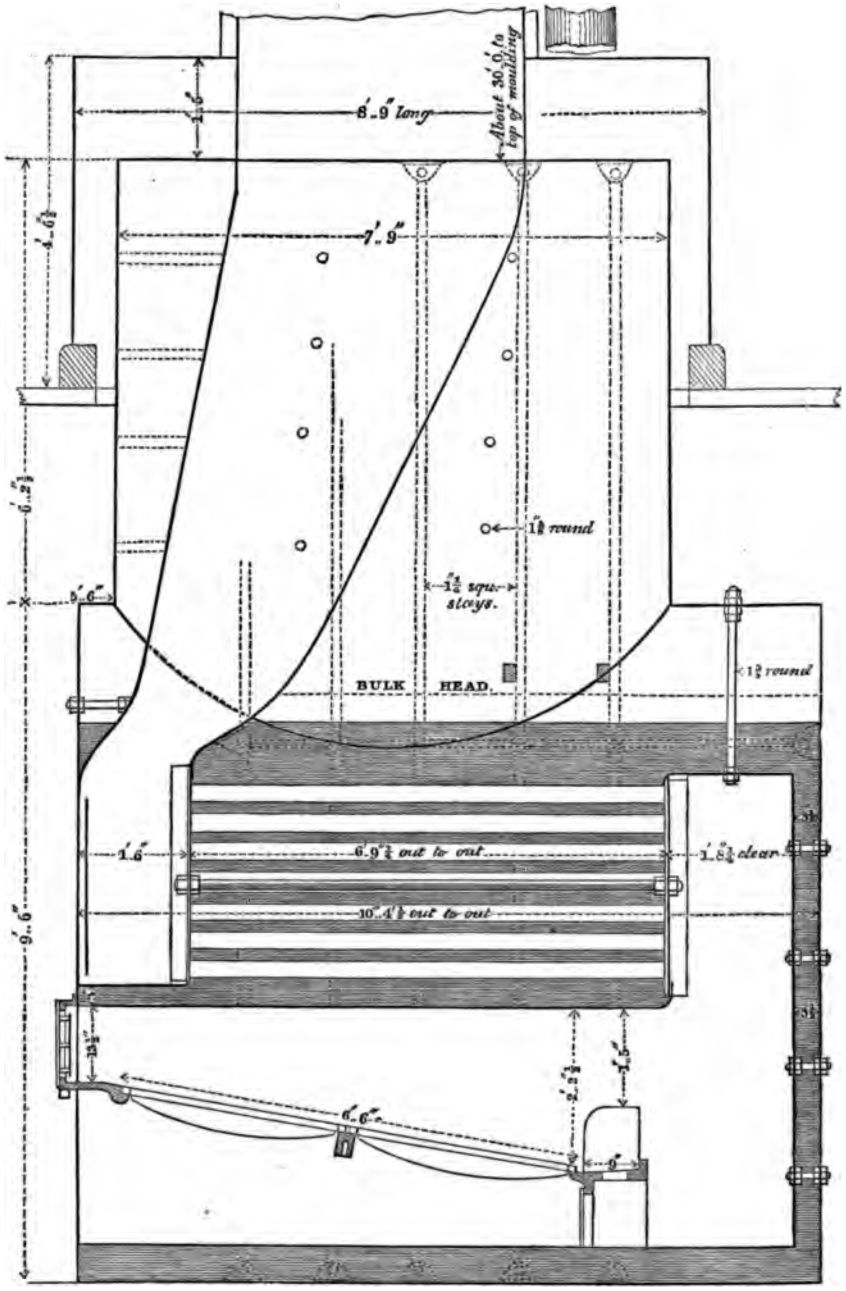
Scale nine sixty-fourths inch=1 foot.

PRESENT BOILERS OF THE STEAMER TAGUS, BY MESSRS. MILLER, RAVENHILL, AND CO., 1844.

Elevation and Transverse Section through Furnace.

End View and Transverse Section through aftermost Smoke-box.

Fig. 102.



Scale three-eighths inch=1 foot.

BOILERS OF THE STEAMER MADRID, BY MESSRS. MILLER, RAVENHILL, AND CO.

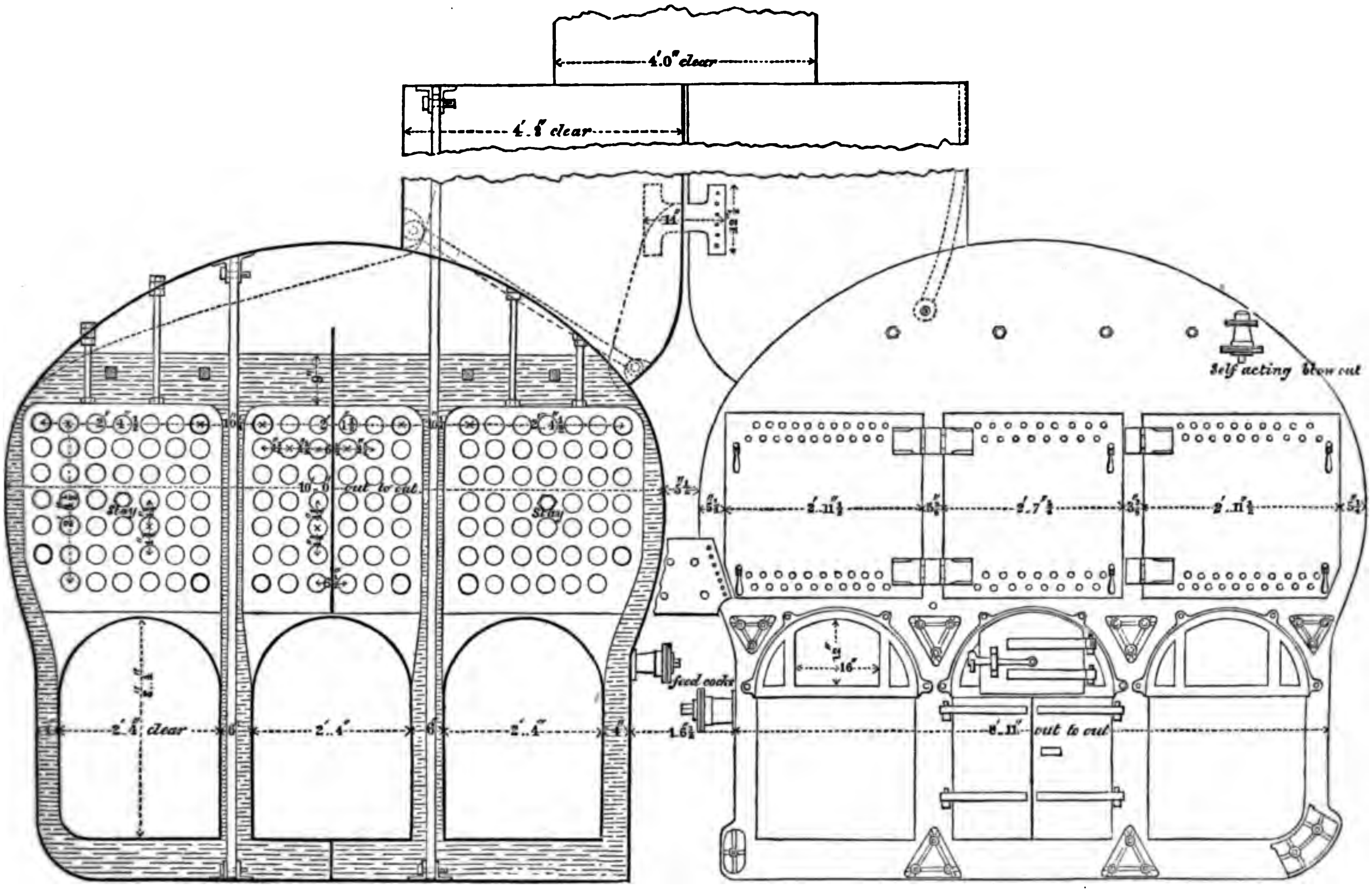
Longitudinal Section.

Figs. 102 and 103 represent upon a larger scale a set of tubular boilers constructed by Messrs. Miller, Ravenhill, & Co., for the steamer Madrid. These drawings so completely illustrate themselves that they do not require any description.

Figs. 104 to 109 illustrate the causes of explosion of a tubular boiler in the steamer Cricket, a small vessel plying upon the Thames. The causes of this accident were ably investigated by Mr. Baker in a series of articles published in the Mining Journal, from which paper these cuts are taken. Mr. Baker very clearly shewed that the explosion had its origin in a gross malformation of the boiler, whereby its strength was impaired, while the safety valves were at the same time prevented from acting efficiently, so that no ordinary amount of careful management could have imparted safety to such a boiler.

Fig. 104 is a longitudinal section of the boiler of the Cricket in its original state. A, is the bottom of the funnel; B, the steam dome; C, the safety valve chest fitted with Salter's spring balance acting on the end of a lever; D, waste steam pipe; E, casing over steam dome; F, blast pipe; G, furnace; H, H, H, tubes; J, lower part of ash-pit, the plate of which, originally $\frac{3}{8}$ths thick, was wasted by corrosion from leakage, &c., until it was only $\frac{1}{16}$ths thick when the rupture

Fig. 103.



Scale three eighths inch=1 foot.

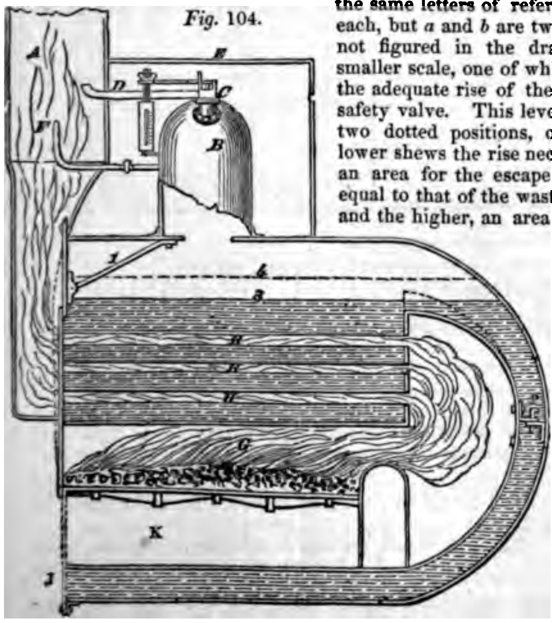
BOILERS OF THE STEAMER MADRID, BY MESSRS. MILLER, RAVENHILL, AND CO.

Transverse section.

Elevation.

took place; K, ash pit; 3, water level; 4, level of water at second gauge cock, 4 inches higher. The dotted lines at the front of the boiler, and at the top of the fire box, shew the bulging and distortion which had taken place long prior to the explosion.

Fig. 104.



Scale three eighths inch=1 foot.

BOILER OF STEAMER CRICKET.

Longitudinal Section.

Fig. 107 is an enlargement of a part of the boiler shewn in *fig.* 104, and the same letters of reference apply to each, but *a* and *b* are two angle irons, not figured in the drawing on the smaller scale, one of which prevented the adequate rise of the lever of the safety valve. This lever is shewn in two dotted positions, of which the lower shews the rise necessary to give an area for the escape of the steam equal to that of the waste steam pipe, and the higher, an area equal to that of the valve itself.

Fig. 105 is a ground plan of the lower part of a stay of angle iron for connecting the outer and inner shell, shewn at 2, *fig.* 104; and *fig.* 106 shews the upper part of the same stay with the head of a pin which projected through it, but which pin did not enter the corresponding hole of the lower stay. *Figs.* 108 and 109 are perpendicular sections of the same stay, as fixed at first, and as displaced prior to the destruction of the boiler.

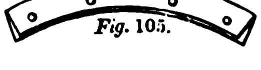


Fig. 105.

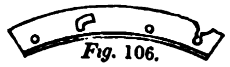
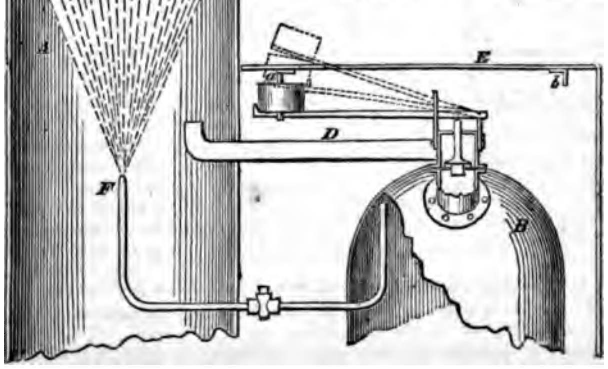


Fig. 106.

A, is the hemispherical shell at back of boiler; B, back of tube box; C, four rivets which appear to have been intended for the attachment of the angle iron, which however was placed 3 inches higher; D, in *fig.* 108, shews in what way another angle iron should have been placed to make the stay efficient. Mr. Baker has proved that by the displacement shewn in *fig.* 109, the internal part of the boiler acted as a lever to rupture the boiler at J, and this action conjoined with the pressure of the steam, which

Fig. 107.



BLAST PIPE AND SAFETY VALVE OF STEAMER CRICKET.

Illustrative of Causes of Explosion.

Fig. 108.

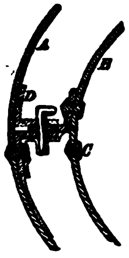
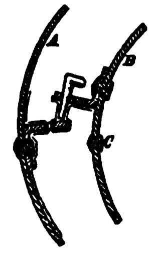
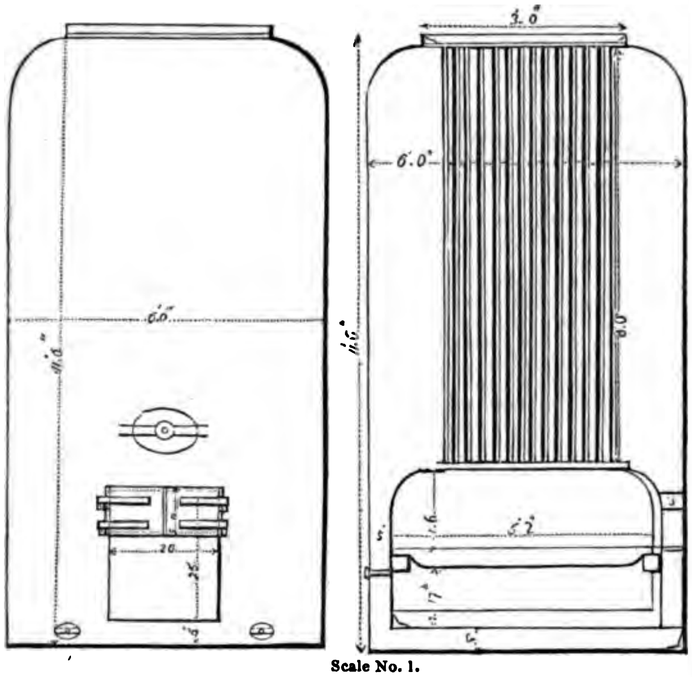


Fig. 109.



was prevented from escaping freely, burst the back and front parts of the boiler asunder; the front and internal parts of the boiler being forced forward until arrested by the engine, and the whole of the shell of the boiler except the front, being projected through the cabins out at the stern of the ship, rending the sides of the vessel asunder during its advance.

Figs. 110, 111.

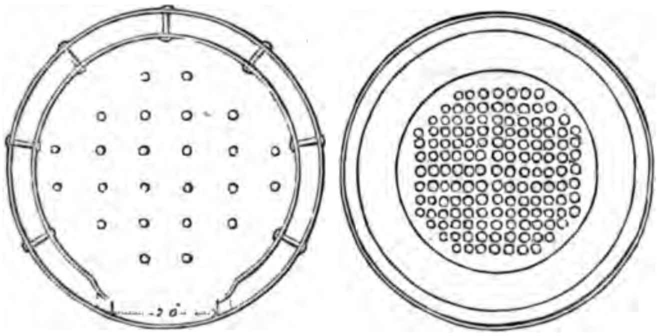


Scale No. 1.

CYLINDRICAL BOILER WITH UPRIGHT TUBES.

Elevation. Perpendicular Section.

Figs. 112, 113.



Scale No. 1.

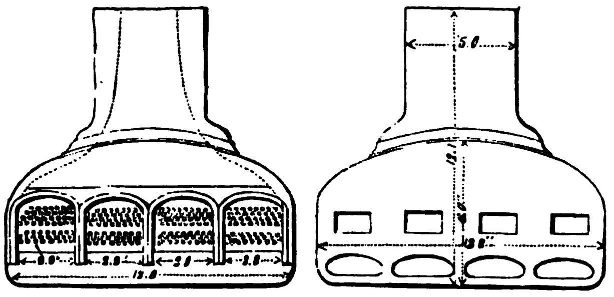
CYLINDRICAL BOILER WITH UPRIGHT TUBES.

Section through Ashpit, showing stays of bottom water space. Section through tubes.

Figs. 110, 111, 112, and 113. represent a marine boiler with upright tubes, a kind of boiler to which we have already made several allusions, and which, we are persuaded, will before long come into extensive use. This boiler, it will be remarked, has the water *outside* of the tubes, and the upper portion of the tubes does not pass through the water, but only through the steam, by which the steam is thoroughly dried, and any inconvenience from priming counteracted. We have another specimen of this boiler to give, and shall reserve what we have to say about the plan until we come to it.

Figs. 114, 115, 116, 117, 118, and 119. represent the boilers of the Queen steamer, a river vessel, constructed by Messrs. Rennie, and well known for her swiftness and efficiency. The object this boiler seeks to attain is lightness, and it is therefore made so as to hold very little water. It does not, however, appear to be well calculated to sustain any considerable pressure, though this is an object of importance in vessels intended to go fast. The following are some of the principal dimensions:— Length 13′ 8″; breadth 12′ 8″; height 6′ 0″; length of furnaces 5′ 2″; length of tubes 5′ 7″; breadth of furnaces 2′ 8″; diameter of tubes 2½; material of tubes brass. Total number of tubes 228. Diameter of cylinder of engines 29¼; length of stroke 4′ 6″. There are two engines on the direct action plan. Collective power 76 horses.

Figs. 114, 115.

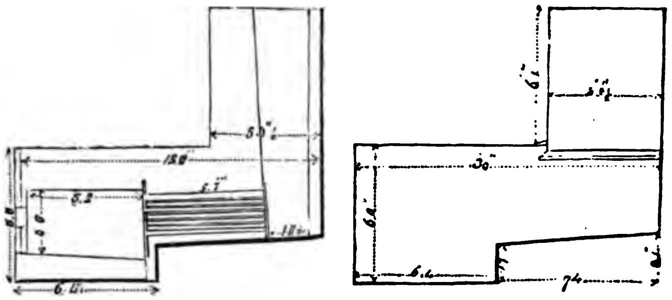


Scale one-eighth inch=1 foot.

BOILERS OF THE QUEEN STEAMER BY MESSRS. RENNIE.

Transverse Section. Elevation.

Figs. 116, 117.



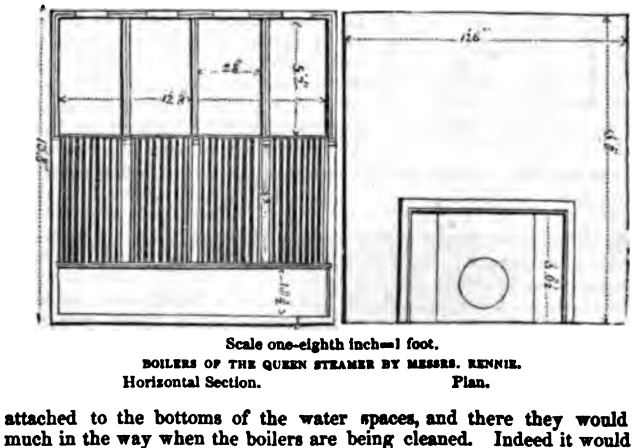
Scale one-eighth inch=1 foot.

BOILERS OF THE QUEEN STEAMER BY MESSRS. RENNIE.

Longitudinal Section. Elevation.

If any considerable pressure of steam be employed in this boiler, it will be necessary to stay down the boiler top very firmly, both to the tops of the furnaces and the bottom of the boiler; for the force acting against the boiler top, and tending to raise it upwards, will be immense, if a high pressure be adopted. To stay the boiler top to the tops of the furnaces alone would not be sufficient, for the tops of the furnaces might alter their form, and the stays would then be of very little avail. The stays to the bottom of the boiler, however, if carried in the usual way, would have to be attached to the bottoms of the water spaces, and there they would be much in the way when the boilers are being cleaned. Indeed it would be almost impossible to clean out the water legs effectually with stays so situated, and the best method, therefore, appears to be either to stay the boiler top to a strong inverted arch spanning the water spaces, or to place a suc-

Figs. 118, 119.



Scale one-eighth inch=1 foot.

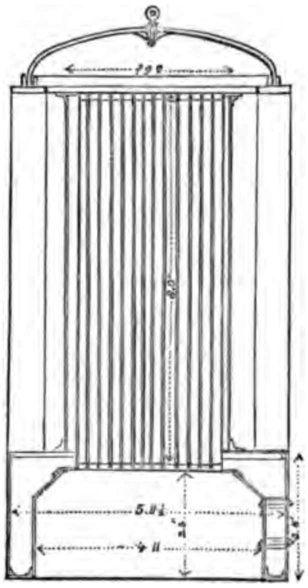
BOILERS OF THE QUEEN STEAMER BY MESSRS. RENNIE.

Horizontal Section. Plan.

cession of iron arches over the furnace tops, to keep them in shape after the fashion practised in Stephenson's locomotives, and to stay the boiler top to these.

Figs. 120, 121. represent another boiler with upright tubes (having the water outside of them), the design of Messrs. Rennie. This boiler is intended to supply steam to an engine on land, and its exterior is therefore composed of a cylinder of brick-work, between which and the boiler shell the smoke is made to circulate on its way to the chimney. This brick cylinder is surmounted by a cast-iron dome, the edge of which fits into a groove containing sand, and access can readily be had to the ends of the tubes by raising up this dome by the tackle applied to the eye fixed in its centre. This kind of boiler is identical in all its important features with that represented in *figs.* 110, 111, 112, and 113. That boiler, however, is intended for a steam vessel, and is, indeed, the boiler of one of the tug vessels working upon the Thames. As we happen to have a very high opinion of this variety of boiler, we must consider its merits in some detail, and therefore refer back our readers to *figs.* 110, 111, 112, and 113, as it is to that specimen our remarks chiefly apply.

Fig. 120.

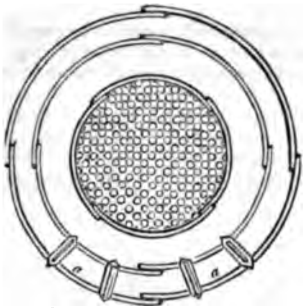


Scale quarter inch=1 foot.

LAND BOILER WITH UPRIGHT TUBES, BY MESSRS. RENNIE.

Perpendicular Section.

Fig. 121.



Scale quarter inch=1 foot.

a Furnace Door. *a* Furnace Door.

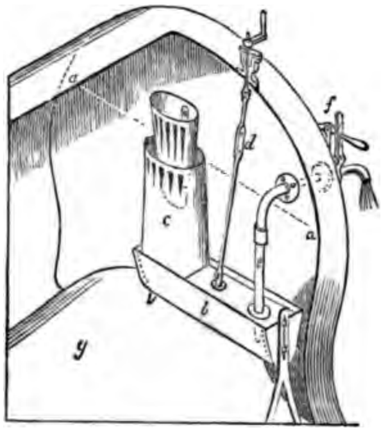
LAND BOILER WITH UPRIGHT TUBES, BY MESSRS. RENNIE.

Transverse Section.

The diameter of that boiler is 6 feet; height, 11 feet 6 inches; diameter of fire-box, 5 feet 2 inches; distance from top of bars to lower tube plate, 1 foot 6 inches; distance from top of bars to ashpit bottom, 1 foot 7 inches; length of tubes, 8 feet; diameter of tubes, 2 inches; distance from centre to centre of tubes, 3 inches; diameter of tube plate, 3 feet 10 inches. There is a clear space of 1 foot 2 inches all round, between the tubes and the boiler shell. The height to which the water rises along the tubes is 5 feet, leaving 3 feet of the tubes to traverse the steam space. There are 145 tubes in all, and, reckoning their effective length at 5 feet, the effective tube surface is 381·53 feet. The fire-box surface is 20·96 feet, making a total of 412·03 square feet of effective heating surface. The area of the fire-grate is 20·96, and the proportion of fire to heating surface is 1 to 20 nearly. One of these boilers supplies the engine of the vessel with steam, the cylinder of which is 26 inches in diameter, and the length of stroke 38 inches, the number of strokes per minute, 35 light, 26 to 30 when towing. The consumption of fuel is 10 cwt. of coal per four hours, including getting up steam. The tubes are of iron, and show no symptoms of injury from the application of heat above the water level. In some of the boilers constructed on this plan the lower tube plate has cracked between the tubes, and we think the breadth of an inch of iron between the tubes is insufficient in most cases. It would be an improvement, we think, to zigzag the tubes, which would leave more iron between the tubes, and, at the same time, would not prevent the introduction of an instrument to scrape them when necessary, at least diagonally. It would be very expedient, too, to defend the tube plate from the heat of the fire by a fire-brick dome perforated opposite to each tube. In that case, however, it would be necessary to give an additional tube surface, as more heat would then pass into the tubes than if such a dome were not employed. It is one drawback to the merits of this boiler, that it will be liable we fear to corrode internally more rapidly than common boilers. One of the most influential causes of internal corrosion appears to be the existence of surcharged steam within the boiler, and in this kind of boiler the steam is almost necessarily surcharged to some extent. The surcharging, however, will be less considerable if there be a large heating surface, which may easily be given. It will be necessary in applying boilers of this construction to steam vessels to adopt means of blowing out the supersalted water very effectually, else the scale may fall from the tubes upon the tube plate, and occasion injury.

One very obvious objection to this plan of boiler will present itself to our practical readers, which is, that a deposit either of silt or scale will be liable to take place on the top of the tube plate, which will, in consequence, very soon burn out. This evil is to a great extent met by our suggestion to interpose a fire-brick dome between the tube plate and the fire; but we have not been able to discover that any sensible inconvenience has arisen from such depositures in boilers of this construction, even without the expedient we have just described. The agitation of the water, caused by the ascent of the steam up through it, is a powerful antidote to any settlement where it is going on, and the particles of matter mingled with the water, and out of which scale is fabricated, find their way by degrees to the sides of the boiler, where the water is tranquil, and there they finally settle. It is expedient, however, in boilers of this kind, either to blow off very frequently, or to have brine pumps, which change the water in the boiler rather faster than usual. It would be a further improvement to place a collecting vessel within each boiler. Instruments of this kind have hitherto been very little used in steam vessels, but in land boilers they have long been employed with advantage, though in that case the advantage is of less account. We shall at a more advanced stage of our progress give some specimens of collecting vessels as applicable to marine boilers, but may here, for the sake of making our recommendation intelligible, explain the simplest form of collecting vessel as applied to waggon boilers.

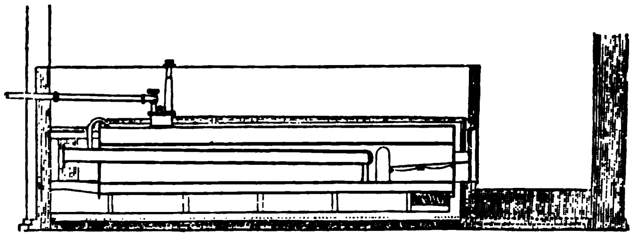
Fig. 122.



ISOMETRICAL VIEW OF WAGGON BOILER WITH SEDIMENT COLLECTOR, BY R. ARMSTRONG, MANCHESTER.

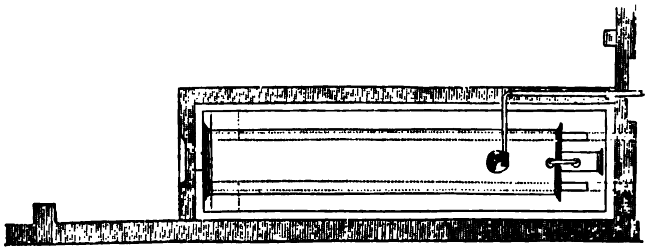
We must first, however, premise that the addition of particles of extraneous matter to boiling water facilitates the extrication of the steam, and, in many cases, lowers the temperature at which ebullition is carried on. The generation of steam is most active in those situations where those particles exist, so that, indeed, the steam appears as if it came out of them, and the particles are continually buoyed up by the steam in its ascent, and prevented from settling where the ebullition is active. If a vessel with a narrow mouth be immerged in a boiler under such circumstances as to preserve the water within it in a tranquil state, the vessel will speedily become filled with depositure resembling mortar, which, could it have settled, would have been indurated into scale. Of this circumstance advantage is taken in the construction of collecting vessels, for if the whole of the water in a boiler be in a state of ebullition except a portion contained in an internal vessel, into that vessel the depositure will find its way, and from thence it may be removed by blowing out. *Fig.* 122. represents a collecting vessel attached to a common waggon boiler which will illustrate the means of applying these principles in practice. *a a* represents the boiler, which has been cut, and a part removed for the purpose of showing the interior. *b* is a box into which the depositure falls through the neck *c*, within which is another cylinder, or rather frustrum of a cone, which may be raised or lowered to suit the water level and other circumstances. These parts are all made of sheet iron. *d* is an agitator for stirring up the depositure within the box previously to blowing out, for which purpose a rod passes through a stuffing box on the boiler top furnished with a handle, which may be turned round. *e* represents the pipe through which the depositure is discharged, *f* the blow-off cock, and *g* the bottom of the boiler. It would be easy in a boiler with upright tubes to convert one or more of the tubes into collecting mouths leading to a sediment vessel underneath.

Fig. 123.



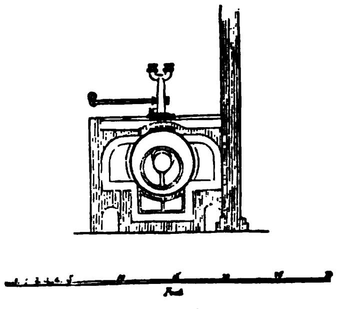
CORNISH BOILER AT MR. THOMAS CUBITT'S FACTORY, BY MESSRS. RENNIE.
Longitudinal Section.

Fig. 124.



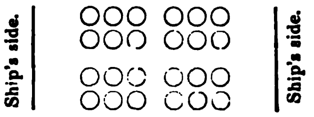
CORNISH BOILER AT MR. THOMAS CUBITT'S FACTORY, BY MESSRS. RENNIE.
Bird's Eye View.

Fig. 125.



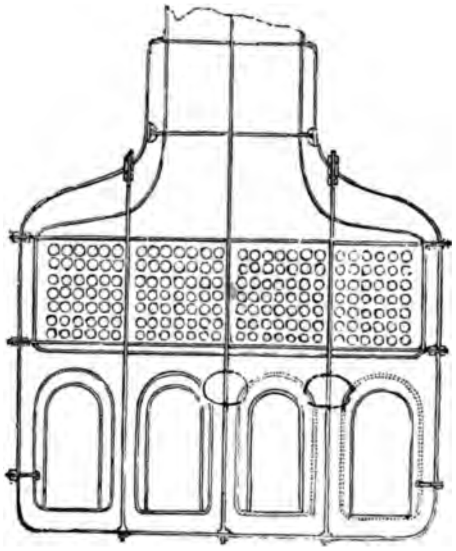
CORNISH BOILER AT MR. THOMAS CUBITT'S FACTORY, BY MESSRS. RENNIE.
Transverse Section.

The remarks which we have already made respecting this species of boiler are sufficient, we conceive, to show that the objections which might be brought against it are not of an insuperable character. Its recommendations, however, are not of a negative kind, and it possesses two of weight enough, we conceive, to entitle it to a preference over most kinds hitherto projected. The first is, that if the steam be taken off by a perforated pipe there will be but little priming; and the second, that the construction facilitates the introduction of the revolving grate described in page 53, and which, we anticipate will come into general use for steam vessels. There is nothing in the revolving grate too complicated for such an application, and it would be a matter of great importance to have the furnaces of steam vessels feeding themselves, which they would do much more effectually, and much more cheaply, than can be done by hand. Boilers on this upright plan might be ranged across the vessel thus,



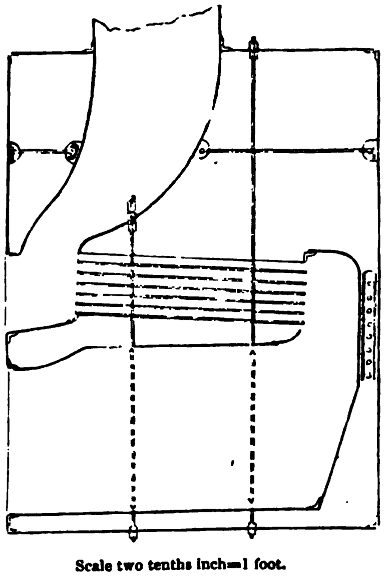
with a crucial passage between them, and the athwartship passage need only be of a width sufficient to enable the attendants to light and clean the fires. We cannot here enter into the details of the application, but may remark that in those cases in which it may be inconvenient to drop the coal upon the fire through a slit from the top of the boiler, it will probably be found the best way to combine the boilers, so that one revolving grate will suffice for two sets of tubes, and the coals may then be introduced between the tube cylinders, and immediately over the fire. One material advantage of this arrangement is, that there will be no smoke—a virtue often claimed for the Cornish plan of boiler, but without any title thereto,

Fig. 126.



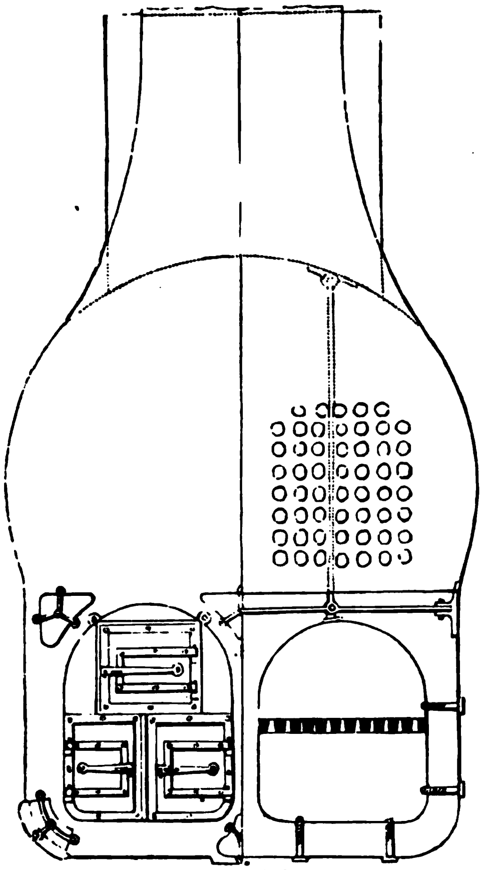
Scale two tenths inch=1 foot.
BOILER OF STEAMER ZEPHYR, BY MESSRS. HORTON AND SON, LIVERPOOL.
Front View and Transverse Section

Fig. 127.



Scale two tenths inch=1 foot.
BOILER OF STEAMER ZEPHYR, BY MESSRS. HORTON AND SON, LIVERPOOL.
Longitudinal Section.

Fig. 128.

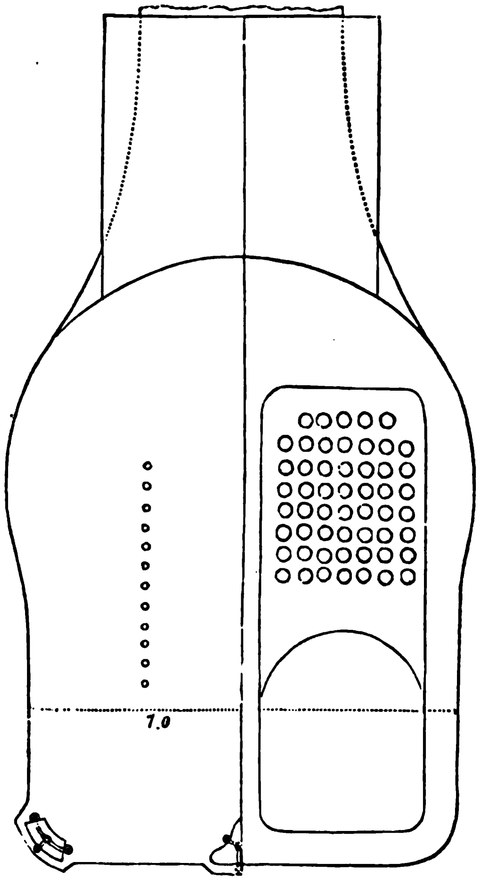


Scale three tenths inch=1 foot.

BOILER OF H. M. STEAMER INFERNAL, BY MESSRS. MILLER, RAVENHILL, AND CO.

Front View one-half in Section.

Fig. 129.



Scale three tenths inch=1 foot·

BOILER OF H. M. STEAMER INFERNAL, BY MESSRS. MILLER, RAVENHILL, AND CO.

Back View one-half in Section.

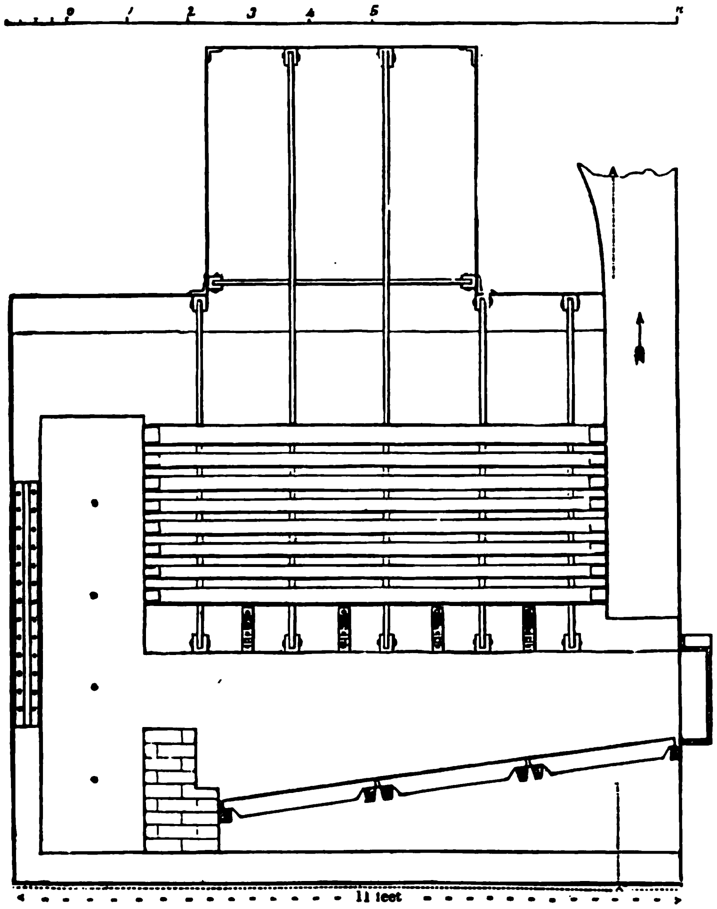
farther than what arises from slow combustion, and the use of Welsh coal, and both of these points may be attained in any boiler. This, we think, will appear clear enough by a reference to the representation of a Cornish boiler given in *figs*. 123, 124, and 125. This boiler produces no smoke, but there is no *peculiarity of structure* to bring about such a result, and the whole efficacy arises from a slow combustion and peculiar coal—advantages which are not exclusively Cornish. The diameter of this boiler is 6 feet 6 inches; length 33 feet 6 inches. Length of furnace 6 feet; breadth of furnace 3 feet 10 inches. A tube of about 19 inches in diameter, filled with water, runs through the main flue, which flue is a continuation of the furnace.

Figs. 126. and 127. represent a small tubular boiler constructed by Messrs. Horton and Son for a coasting steamer called the Zephyr. This boiler has been found to perform well, and is, in every respect, satisfactory. The tubes are of iron, 3 inches in diameter, and 6 feet long. Length of furnace 6 feet, number of tubes 168. 2 engines. Consumption of coal per hour, about 6 cwt. The pressure of steam is about 5 lbs. on the square inch.

Figs. 128, 129, and 130. represent another boiler, by Messrs. Miller, Ravenhill, and Co., of the tubular kind. It is identical in all its main features with the boilers of the Tagus already described, and the same remarks apply to it. It has been found expedient to introduce a jet of steam into the chimney of this vessel to quicken the draught. The tubes are of brass, 3¼ inches in diameter, and the tube plates are of iron. A galvanic action between the brass and the iron has been found to arise in some boilers, which shows itself, not at the ends of the tubes, but at the ends of the athwartship stays which bind the sides of the boiler together; and the iron plate around these stays very soon acquires the appearance of having been scooped out by a knife; but in other boilers no action of this kind has been found to take place, and it has been doubted whether a leakage caused by the inadequate fastening of the stays has not had something to do with its production; nevertheless, in several cases of brass tubed boilers which have come under our observation, the action has been very remarkable in the situation we have mentioned. The evil would probably be obviated by the application of a washer of zinc. The experience which has been obtained with tubular boilers since the first publication of the present work, certainly shows that brass tubes are on the whole the most eligible. Iron tubes are speedily eaten into holes by corrosion, and it is remarkable that the corrosion chiefly takes place upon the under side. Brass tubes, on the contrary, are found to last many years. It appears to be the best plan to refrain from attempts at scaling brass tubes, but they may be withdrawn once a year, cleaned and re-inserted.

Figs. 131, 132, and 133. represent the boilers of the steam vessel Ocean. The tubes of these boilers are of iron 3¼ inches in diameter and 9 feet long; furnaces 7 feet long and 2′ 1″ wide. There are three boilers in all: the centre one with three furnaces, and the two wing ones with two furnaces each. Total breadth of boilers 19½ feet; total length 14 feet; total number of tubes 378; two engines—diameter of cylinder 56 inches; length of stroke 5½ feet; pressure of steam about 4¼ lbs; consumption of coal about 18 cwt. per hour. In ordinary coasting vessels we do not approve of the plan of firing from each end, as the length in the vessel occupied by an additional firing space is a manifest waste of room; and there will be no difficulty in short voyages, about maintaining the trim of the ship on account of the stowage of so evanescent a cargo as coal in the wake of the furnaces. The object should, we conceive, be to obtain the requisite number of furnaces in the breadth of the ship, and then to add a sufficient number of tubes above the furnaces to extract the heat given out in them. In cases where this cannot be altogether, and yet can be nearly done it is a less evil, we conceive, to put a few furnaces in a second tier into the midship boiler, rather than change the whole plan of the boiler by firing from both ends. In most cases we believe it will be possible to get sufficient room for the furnaces in the breadth of the ship if the engines be wrought expansively; and this may be done, without affecting the power, either by applying high pressure steam to the existing size of cylinders, or by introducing larger cylinders, and retaining the steam at a moderate pressure—that is, under 10 lbs. The latter plan in the case of new vessels is, in our judgment, greatly the preferable one; and we should recommend all new steam vessels to be made with the cylinders very large, while the boilers remain of the same dimensions as at present, except in the case of vessels impelled by the screw, where the engines may be worked at a very high speed—an increase in the speed being equivalent to an enlargement of the cylinder. A great force is thus available for the propulsion of the vessel when necessary, whether from adverse circumstances of wind and water, or otherwise, merely by diminishing the degree of expansion; while, in fair winds and smooth water, it becomes necessary to work with a very high measure of expansion to keep the engines supplied

Fig. 130.

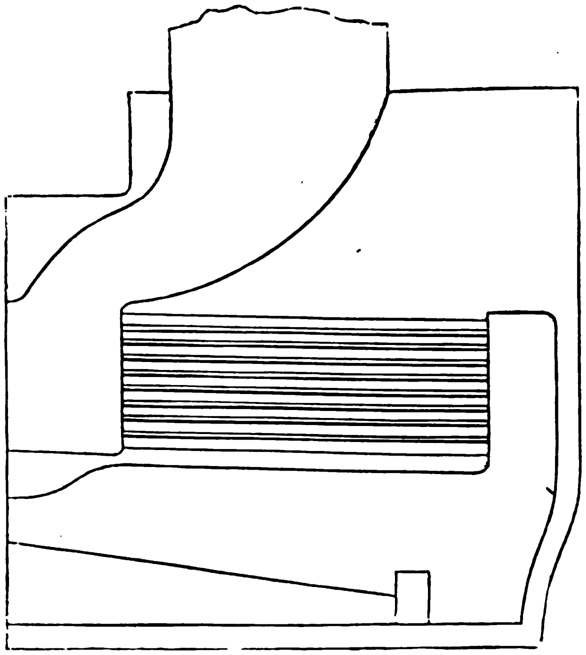


Scale three tenths inch = 1 foot.

BOILER OF H. M. STEAMER INFERNAL, BY MESSRS. MILLER, RAVENHILL, AND CO.

Pependicular Section.

Fig. 131.



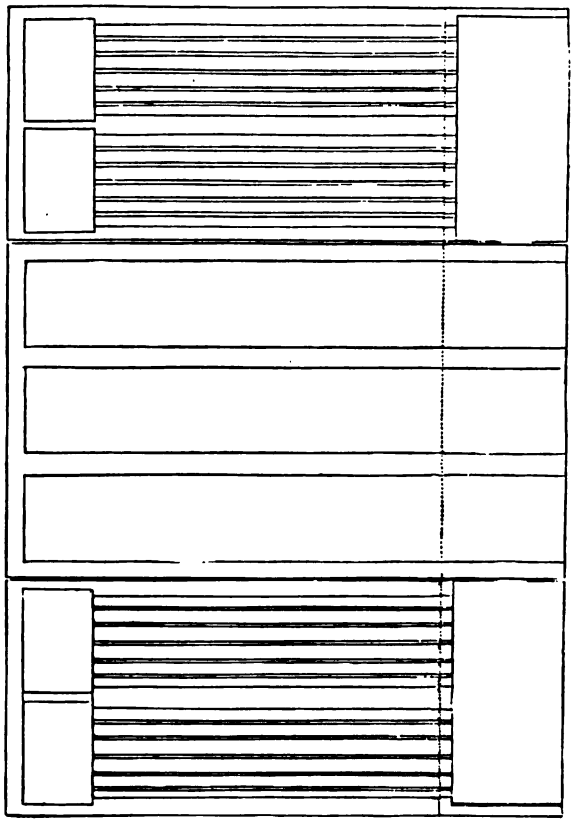
Scale three fourteenths inch = 1 foot.

BOILERS OF THE STEAMER OCEAN, BY MESSRS. HORTON AND SON, LIVERPOOL.

Longitudinal Section.

with steam, thus securing a moderate and uniform consumption. To make the engines light, while the power is kept undiminished, they must be worked with a fast piston; and to make the boilers light, with unimpaired

Fig. 132.

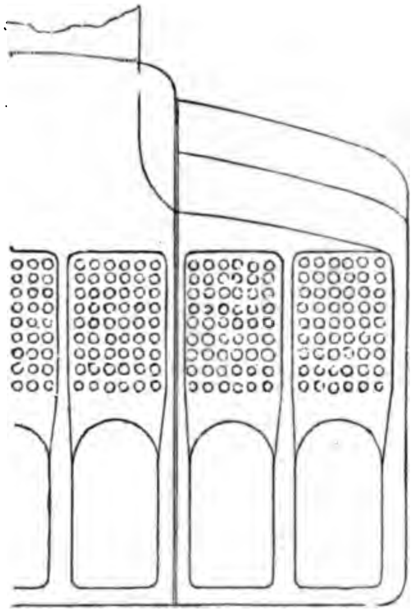


Scale three fourteenths inch = 1 foot.

BOILERS OF THE STEAMER OCEAN, BY MESSRS. HORTON AND SON, LIVERPOOL.

Horizontal Section through Tubes of Wing Boilers and Furnaces of Centre Boiler.

Fig. 133.



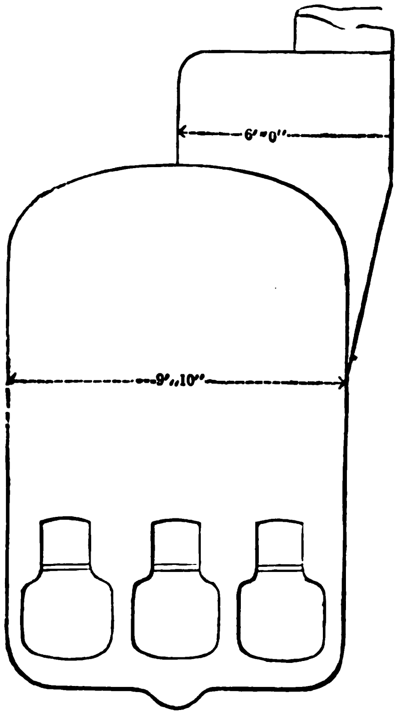
Scale three fourteenths inch = 1 foot.

BOILERS OF THE STEAMER OCEAN, BY MESSRS. HORTON AND SON, LIVERPOOL.

Transverse Section.

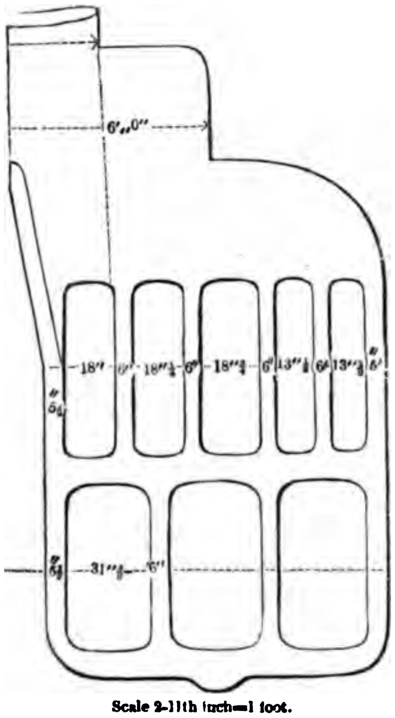
efficacy, they must be provided with an artificial draft, unless the calorimeter or sectional area of flue be made larger than is at present usual in boilers forced in the manner of locomotive boilers. It is doubtful whether the tubes of tubular boilers intended for low pressure engines are not still made longer than is expedient.

Fig. 134.



Scale 2-11th inch=1 foot.
BOILERS OF STEAM SHIP FORTH, BY BURY, CURTIS, AND KENNEDY.
Front View.

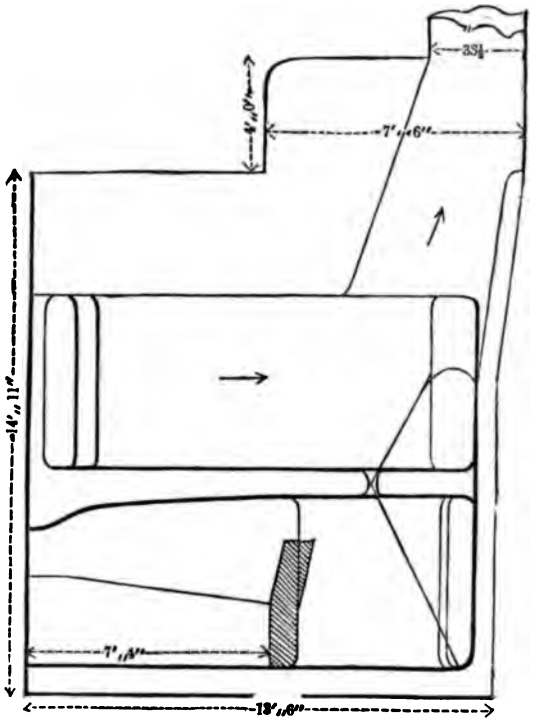
Fig. 135.



Scale 2-11th inch=1 foot.
BOILERS OF STEAM SHIP FORTH, BY BURY, CURTIS, AND KENNEDY.
Transverse Section.

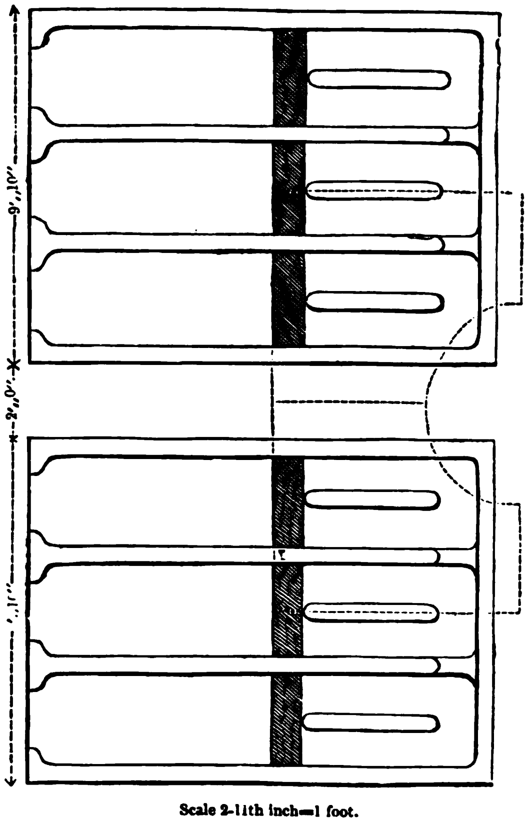
Figs. 134, 135, 136, 137, 138, and 139, are different views of the boilers of the steamer Forth, belonging to the Royal Mail Steam Packet Com-

Fig. 136.



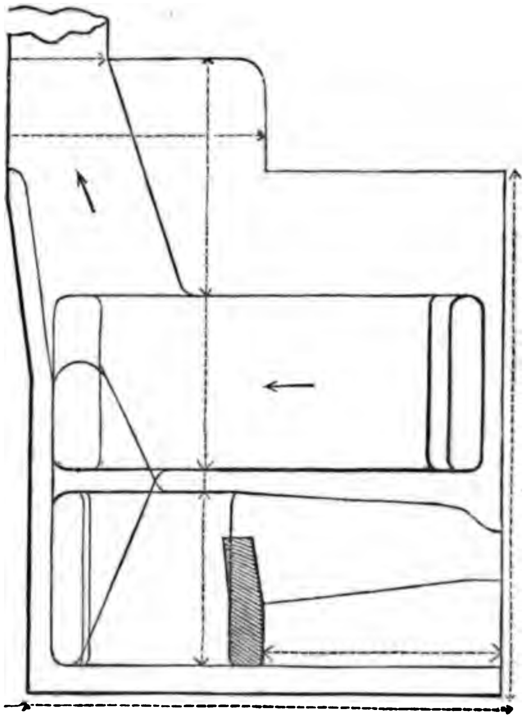
Scale 2-11th inch=1 foot.
BOILERS OF STEAM SHIP FORTH, BY BURY, CURTIS, AND KENNEDY.
Longitudinal Section.

Fig. 137.



Scale 2-11th inch=1 foot.
BOILERS OF STEAM SHIP FORTH, BY BURY, CURTIS, AND KENNEDY.
Horizontal Section through Furnaces.

Fig. 138.

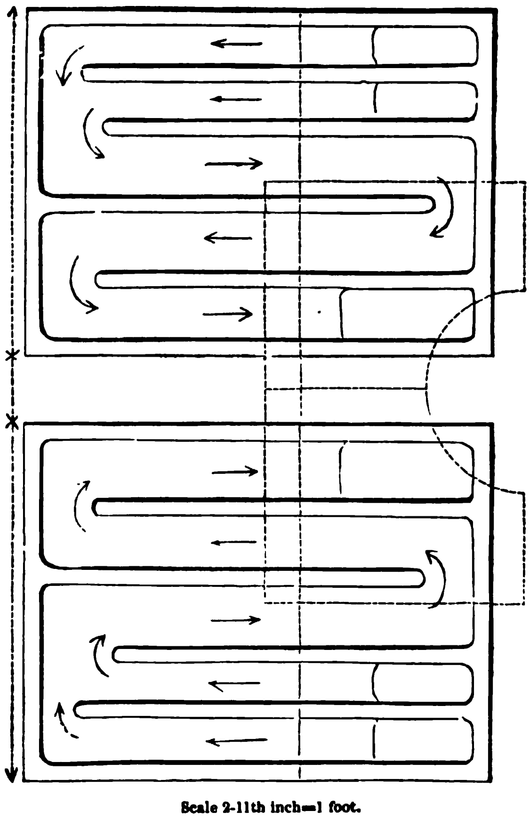


Scale 2-11th inch=1 foot.

BOILERS OF STEAM SHIP FORTH, BY BURY, CURTIS, AND KENNEDY.

Longitudinal Section.

Fig. 139.



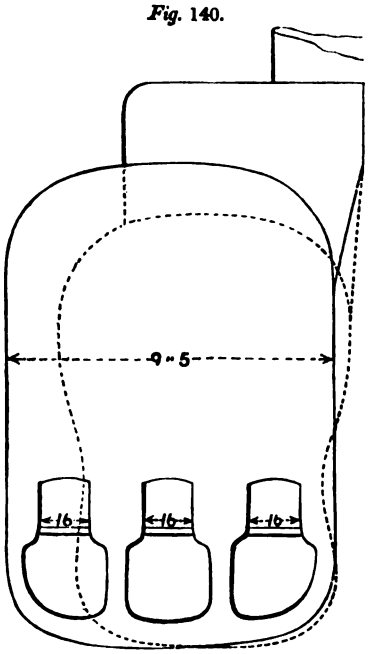
Scale 2-11th inch=1 foot.

BOILERS OF STEAM SHIP FORTH, BY BURY, CURTIS, AND KENNEDY.

Horizontal Section through Flues.

pany. These boilers are well worthy of the attention of the engineer, as they have approved themselves more economical than any of the other boilers employed in those vessels, at the same time that there is an abundance of steam, and the speed of the vessel is well maintained. The following are some of the more important particulars:—There are four boilers, with three furnaces in each, making 12 furnaces in all. Length of each boiler, 13′ 6″; breadth, 9′ 10″; height, 14′ 11″. There is a fore and aft passage between the boilers, 2 feet wide, and an athwart passage 18 inches wide. Length of furnace, 7′ 4″; breadth of furnace, $31\frac{5}{8}$ inches; diameter of chimney, 67 inches; height of flues, 5 feet.

Fig. 140.



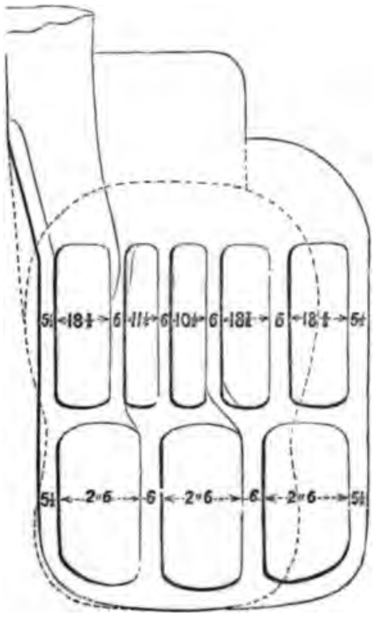
Scale 2-11th inch=1 foot.

BOILERS FOR PRUSSIAN STEAM FRIGATES, BY BURY, CURTIS, AND KENNEDY, 1848.

Elevation.

Figs. 140, 141, 142, 143, 144, and 145, represent two sets of boilers constructed by Messrs. Bury, Curtis, and Kennedy, for the two steam vessels Wladimir and Der Prussicke Adler, the one belonging to the Russian and

Fig. 141.



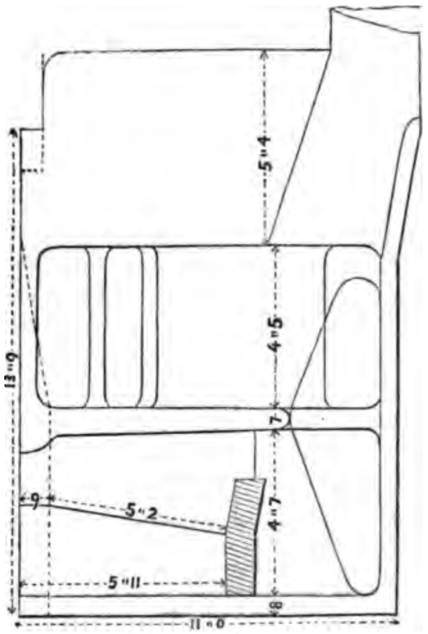
Scale 2-11th inch=1 foot.

BOILERS FOR PRUSSIAN STEAM FRIGATES, BY BURY, CURTIS, AND KENNEDY, 1845

Transverse Section.

the other to the Prussian government, and both of the power of 320 horses. These examples are of much interest, apart from all consideration of the general success of the constructors, the boilers for the Russian vessel being of the tubular variety, while those for the Prussian vessel are on the common flue plan; and we shall thus have a fair comparison of the merits of the two varieties. The shape and dimensions of the tubular boiler are shown

Fig. 142.

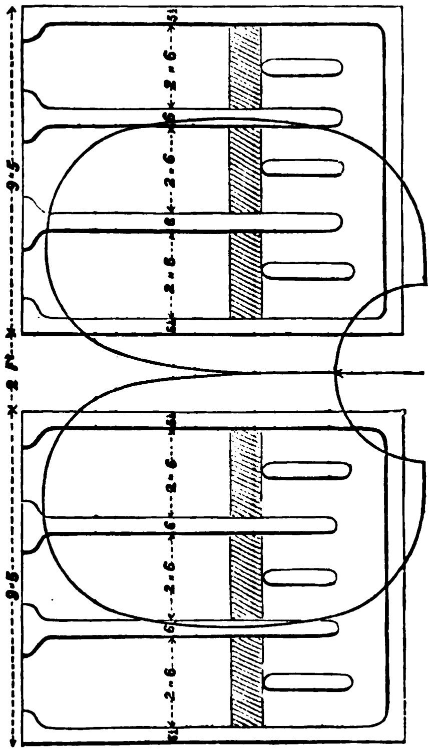


Scale 2-11th inch=1 foot.

BOILERS FOR PRUSSIAN STEAM FRIGATES, BY BURY, CURTIS, AND KENNEDY, 1845.

Transverse Section.

Fig. 143.

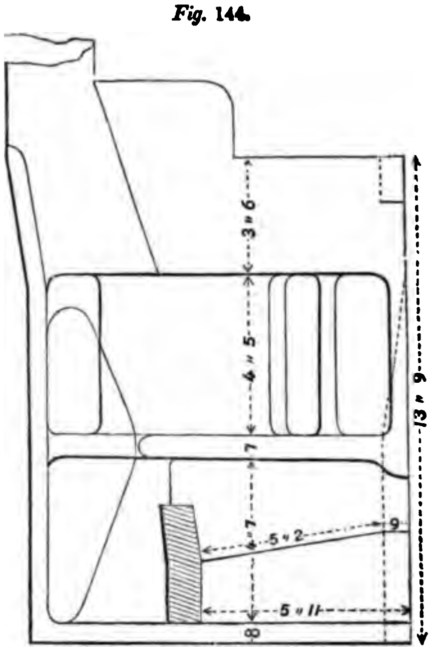


Scale 2-11th inch=1 foot.

BOILERS FOR PRUSSIAN STEAM FRIGATES, BY BURY, CURTIS, AND KENNEDY, 1845.

Horizontal Section through Furnaces.

Fig. 144.

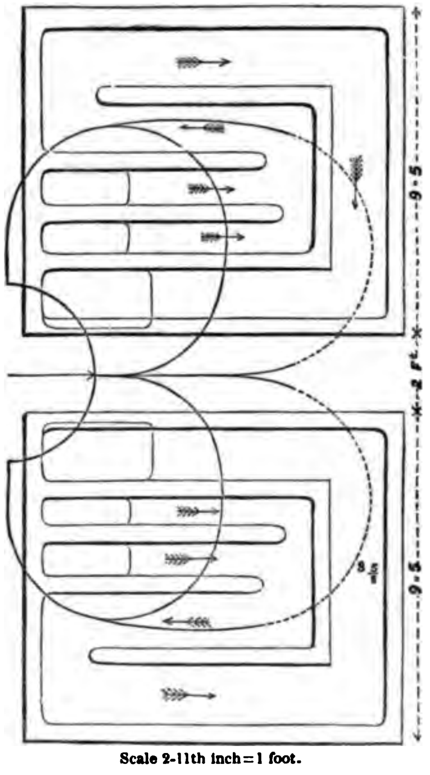


Scale 2-11th inch=1 foot.

BOILERS FOR PRUSSIAN STEAM FRIGATES, BY BURY, CURTIS, AND KENNEDY, 1845.

Transverse Section.

Fig. 145.



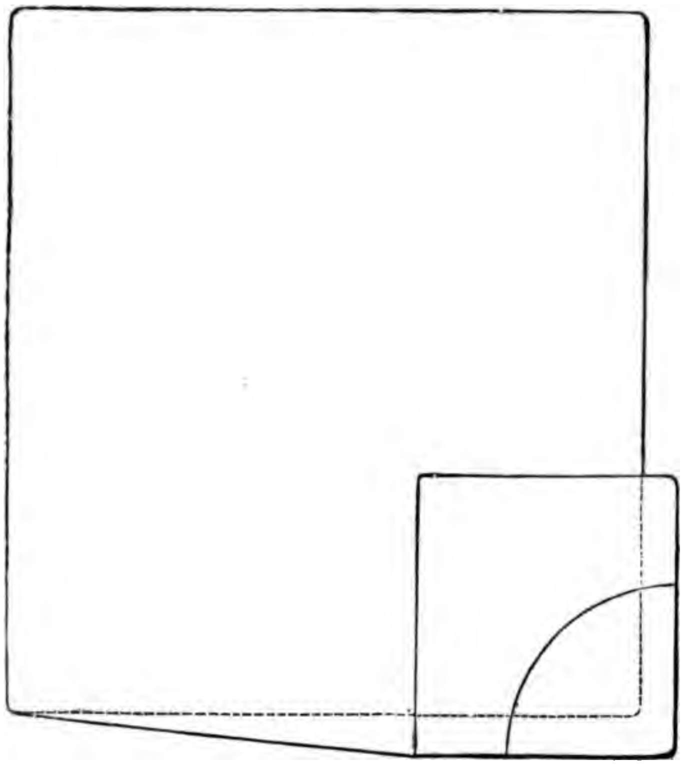
Scale 2-11th inch=1 foot.

BOILERS FOR PRUSSIAN STEAM FRIGATES, BY BURY, CURTIS, AND KENNEDY, 1845.

Horizontal Section through Flues.

in the figures by means of dotted lines; and a just conception may thus be arrived at of the amount of space occupied by a tubular and a flue boiler of the same efficacy in raising steam. The tubular boiler, of which the outline is here given, is almost identical with the boiler of the Braganza steamer, already given, and it is therefore needless here to repeat the delineation.

Fig. 146.

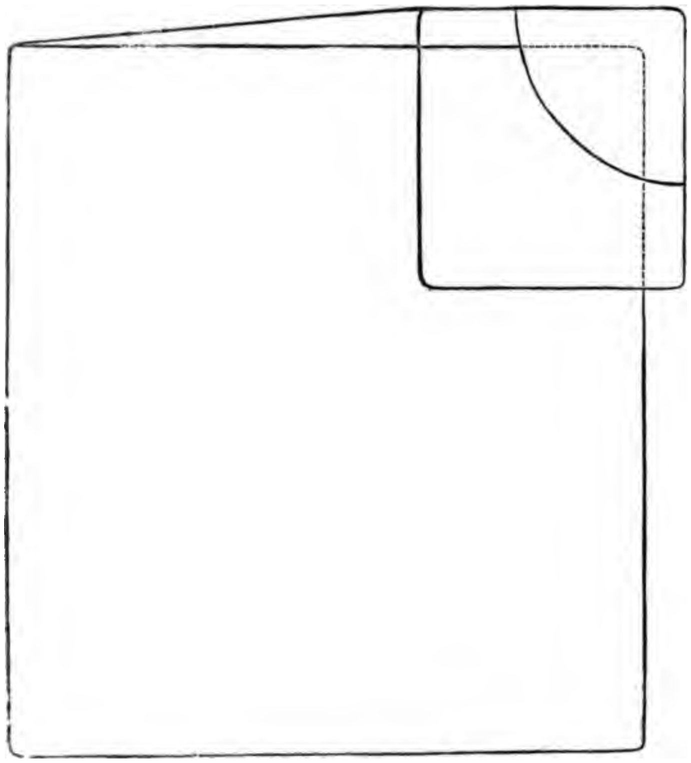


Scale one-quarter inch=1 foot.

BOILERS OF H. M. STEAM VESSEL RETRIBUTION, OF 800 H. P., BY MAUDSLAY, SONS, AND FIELD, 1845.

Bird's-Eye View.

Fig. 147.

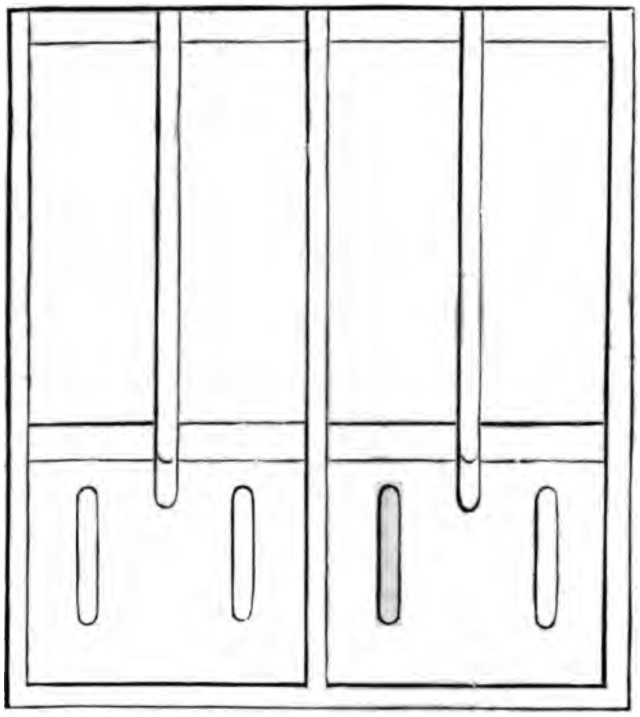


Scale one-quarter inch=1 foot.

BOILERS OF H. M. STEAM VESSEL RETRIBUTION, OF 800 H. P., BY MAUDSLAY, SONS, AND FIELD, 1845.

Bird's-Eye View.

Fig. 148.

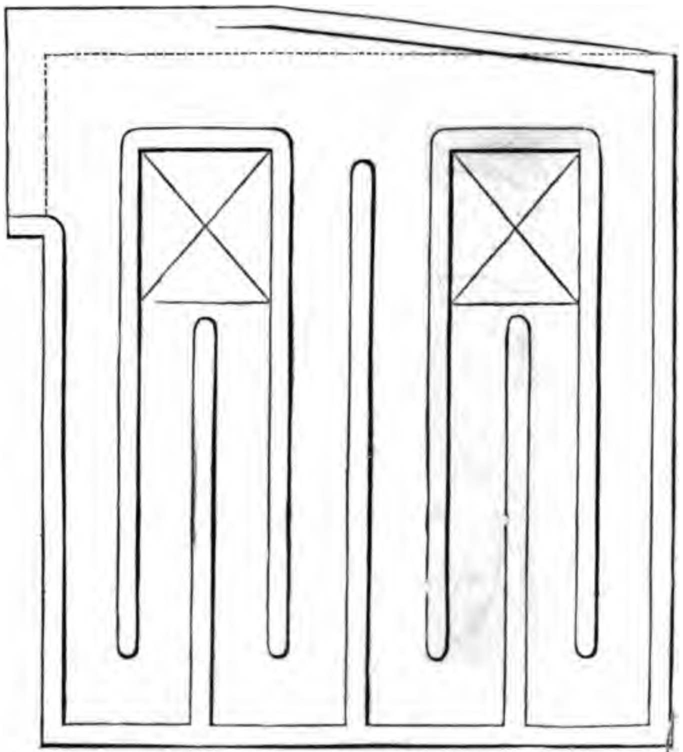


Scale one-quarter inch=1 foot.

BOILERS OF H. M. STEAM VESSEL RETRIBUTION, OF 800 H. P., BY MAUDSLAY, SONS, AND FIELD, 1845.

Horizontal Section through Furnaces.

Fig. 149.

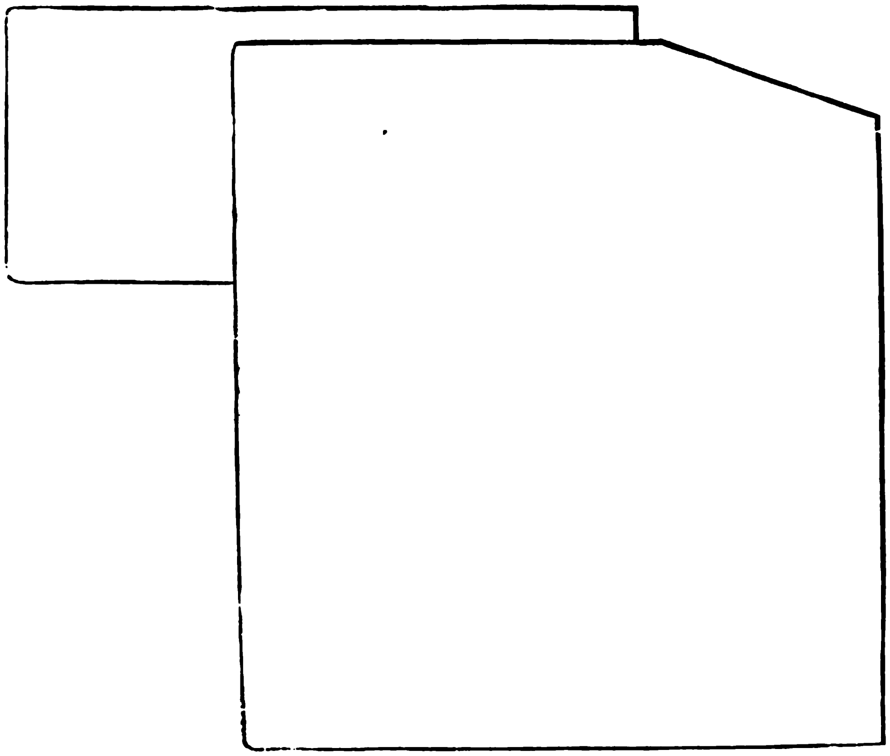


Scale one-quarter inch=1 foot.

BOILERS OF H. M STEAM VESSEL RETRIBUTION, OF 800 H. P., BY MAUDSLAY, SONS, AND FIELD, 1845.

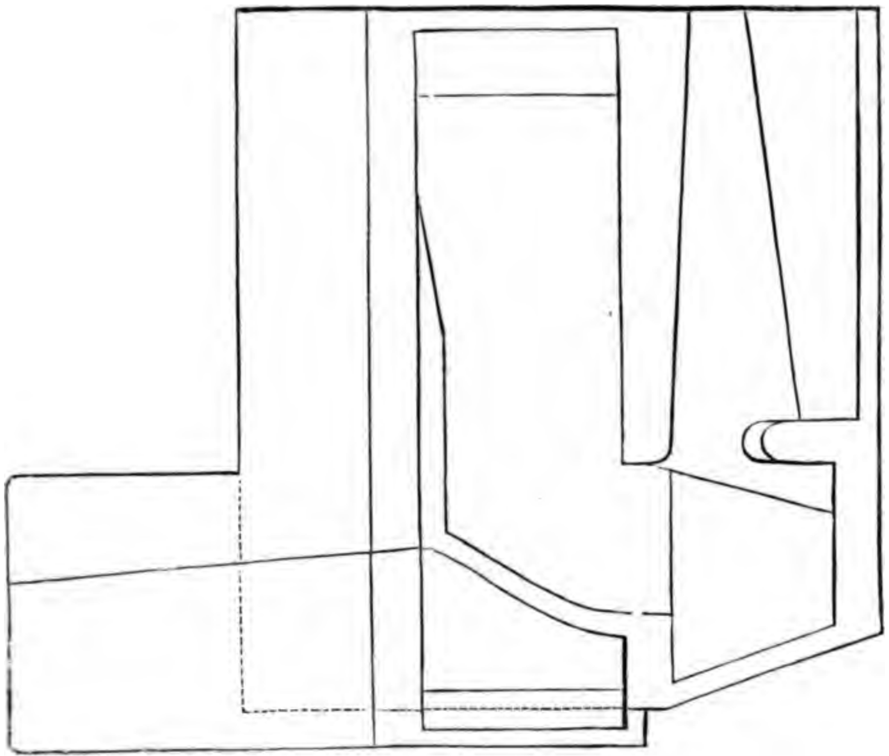
Horizontal Section through Flues.

Fig. 150.



Scale one-quarter inch=1 foot.
BOILERS OF H. M. STEAM VESSEL RETRIBUTION, OF 800 H. P., BY MAUDSLAY, SONS, AND FIELD, 1845.
Side View.

Fig. 151.

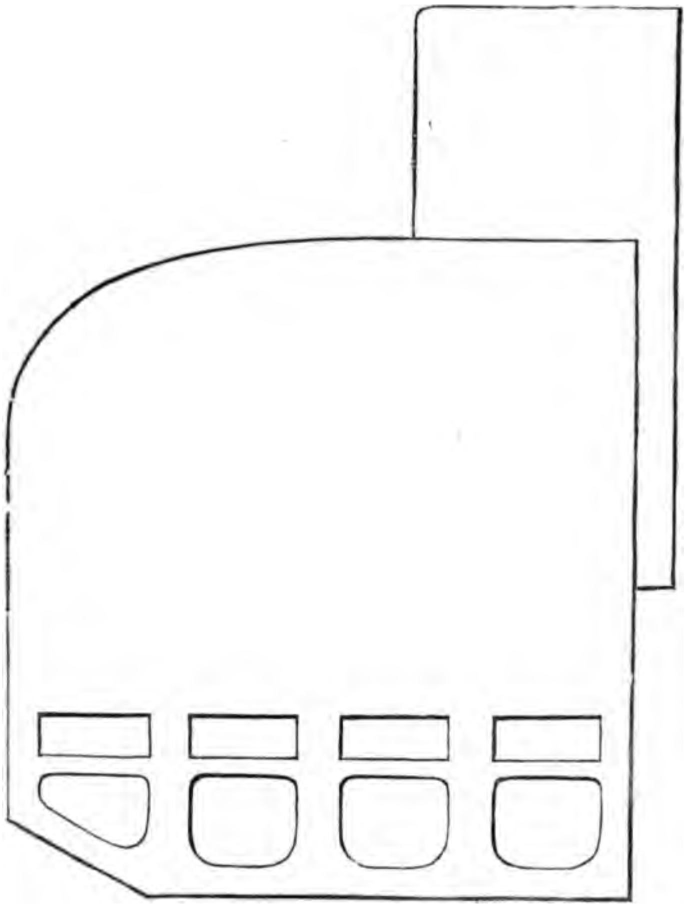


Scale one-quarter inch=1 foot.
BOILERS OF H. M. STEAM VESSEL RETRIBUTION, OF 800 H. P., BY MAUDSLAY, SONS, AND FIELD, 1845.
Longitudinal Section.

Figs. 146, 147, 148, 149, 150, 151, 152, and 153, represent the boilers of the Retribution, a steamer of 800 horse power; the engines being on the double cylinder plan of Messrs. Maudslay. There is nothing very peculiar in these boilers except their size; in other respects they very much resemble the boilers of the Great Western, and of the Thames and Medway, also by Messrs. Maudslay and Field, of which we have already given delineations. *Figs.* 154, 155, 156, 157, 158, 159, and 160, are different views of a sediment collector, as made by Mr. Armstrong of Manchester for marine boilers. The manner in which this contrivance acts has already been explained, and all that we have here to do is to give such forms of the machine as have been found the most convenient in practice. The sediment vessels are generally made of thin sheet iron, and an agitator with a handle extending through a stuffing-box to the outside of the boiler, is usually added to facilitate the blowing out of the silt and other foreign matters caught by the collectors. Of Lamb's scale preventer for marine boilers, an account will be found at page 179. In the manufacturing districts the main purpose for which collecting vessels is employed, is the prevention of priming.

Priming arises from insufficient steam room, an inadequate area of water level, or the use of dirty water in the boiler; the last of these instigations may be remedied by the use of collecting vessels, but the other defects are only to be corrected either by a suitable enlargement of the boiler, or by increasing the pressure and working more expansively. Closing the throttle-valves of an engine partially will generally diminish the amount of priming, and opening the safety-valve suddenly will generally set it astir. A steam vessel coming from salt into fresh water is much more liable to prime than if she had remained in salt water, or never ventured out of fresh. This is to be accounted for by the higher heat at which salt water boils, so that casting fresh water among it is in some measure like casting water among molten metal, and the priming is in this case the effect of the rapid production of steam. One of the best palliatives of priming appears to be the interposition of a perforated plate between the steam space and the water. The water appears to be broken up by dashing against a plate of this description, and the steam is liberated from its embrace. In cases in which an addition is made to a boiler or steam chest, it will be the best way not to cut out a large hole in the boiler shell for establishing a communication with the new chamber, but to bore a number of small holes for this purpose, so as to form a kind of sieve, through which a rush of water cannot ascend. In locomotives the same end is attained by the use of a perforated steam pipe extending from end to end of the boiler. Such a contrivance draws the steam off equally from the surface, instead of taking it from any one part; and boilers provided with it are enabled to work with so small a steam space that the steam domes are now being taken away from locomotives altogether. This expedient has not yet been adopted in steam vessels, though it appears to be applicable to them also with advantage. In some boilers priming appears to be mainly caused by a malformation which prevents the water from circulating freely, and the steam has therefore to pass up through the water, occasioning a great agitation, instead of the water being enabled to circulate with the ascending steam. The evil may be mitigated in such cases by the addition of pipes to the exterior of the boiler, which will permit a descending current to be established, to replace the water carried upward by the steam.

Fig. 152.

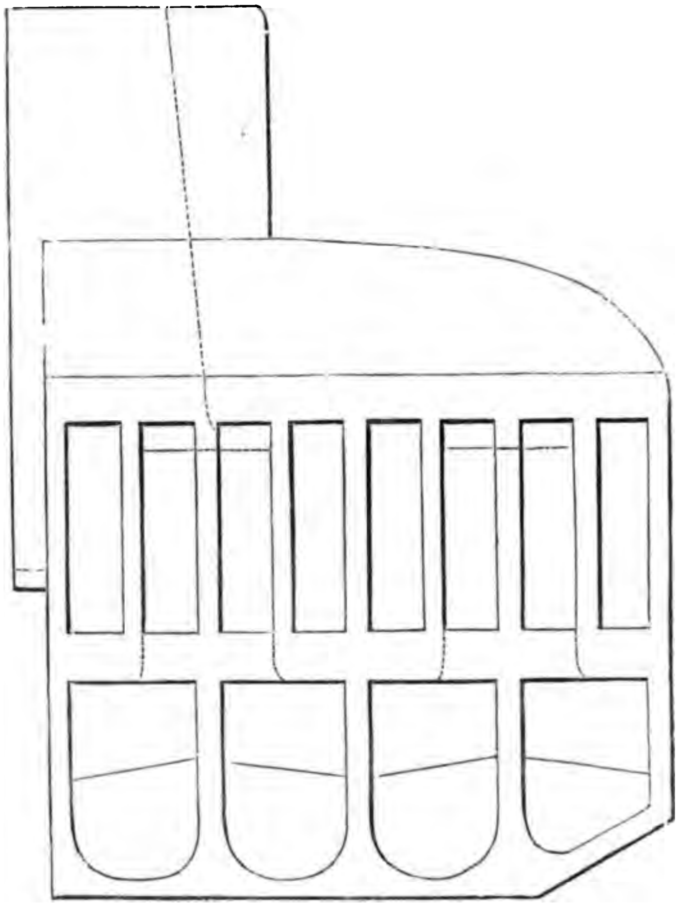


Scale quarter inch = 1 foot.

BOILERS OF H. M. STEAM VESSEL RETRIBUTION, OF 800 H. P., BY MAUDSLAY, SONS, AND FIELD, 1845.

Elevation.

Fig. 153.

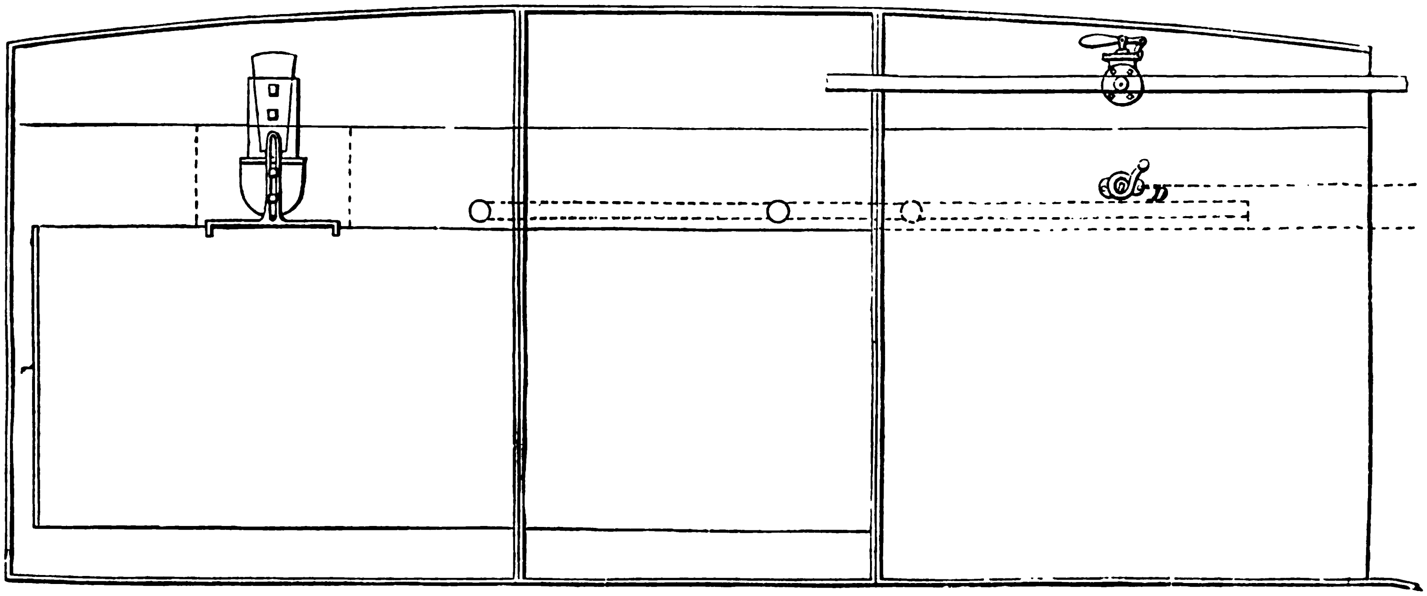


Scale quarter inch = 1 foot.

BOILERS OF H. M. STEAM VESSEL RETRIBUTION, OF 800 H. P., BY MAUDSLAY, SONS, AND FIELD, 1845.

Transverse Section.

Fig. 154.

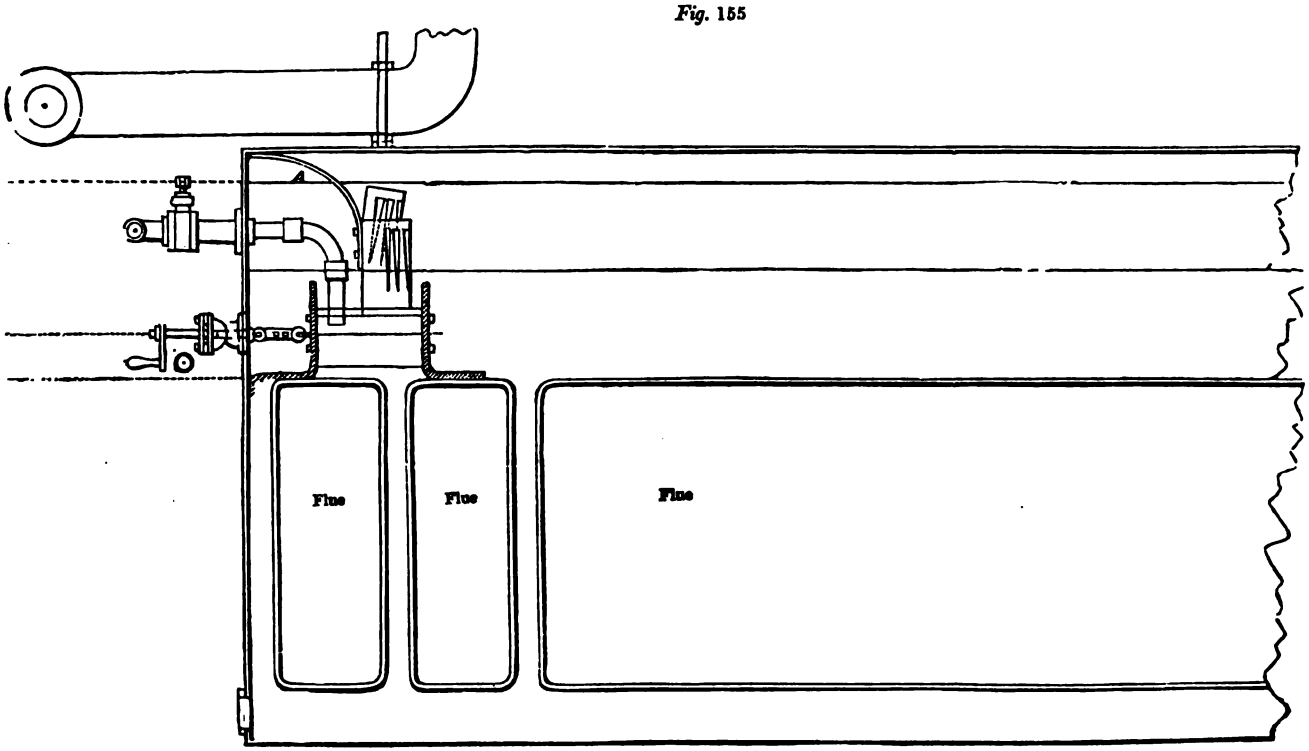


Scale three-eighths inch = 1 foot.

SEDIMENT COLLECTORS, AS APPLIED TO A STEAM VESSEL OF 240 H. P., BY R. ARMSTRONG, MANCHESTER.

Front View of Boilers.

Fig. 155

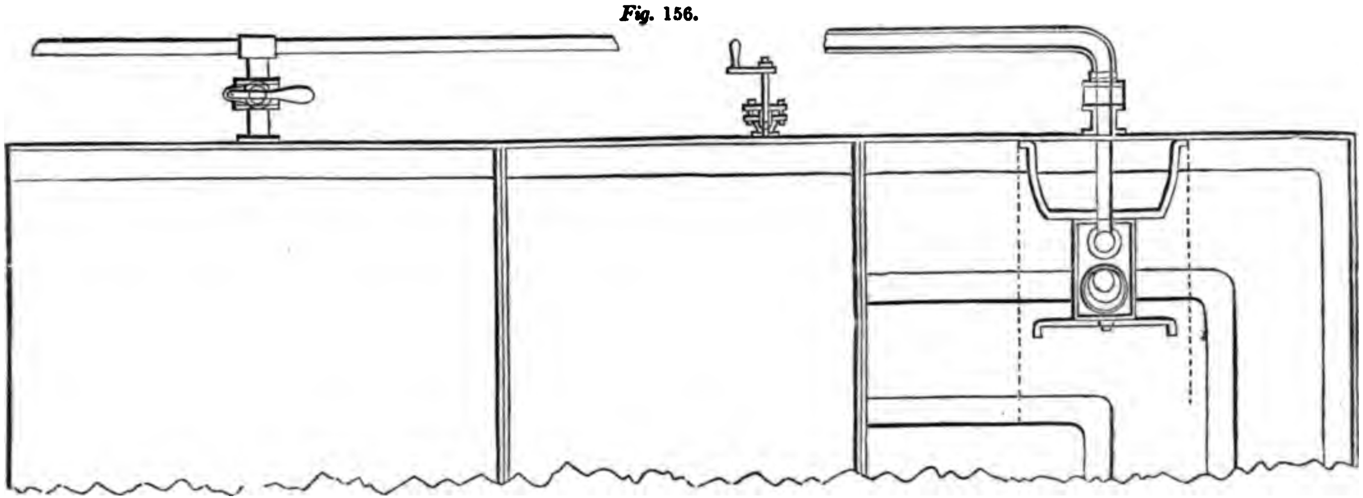


Scale three-eighths inch=1 foot.

SEDIMENT COLLECTORS, AS APPLIED TO A STEAM VESSEL OF 240 H. P., BY R. ARMSTRONG MANCHESTER.

Longitudinal Section of Boilers.

Fig. 156.

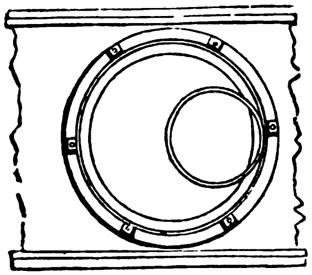


Scale three-eighths inch=1 foot.

SEDIMENT COLLECTORS, AS APPLIED TO A STEAM VESSEL OF 240 H. P., BY R. ARMSTRONG, MANCHESTER.

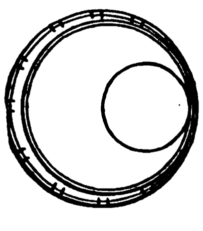
Horisontal Section and Bird's-Eye View.

Fig. 157.



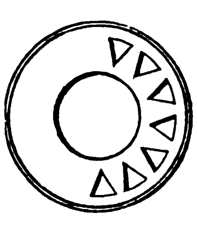
Plan of Collecting Vessel from bottom.

Fig. 158.



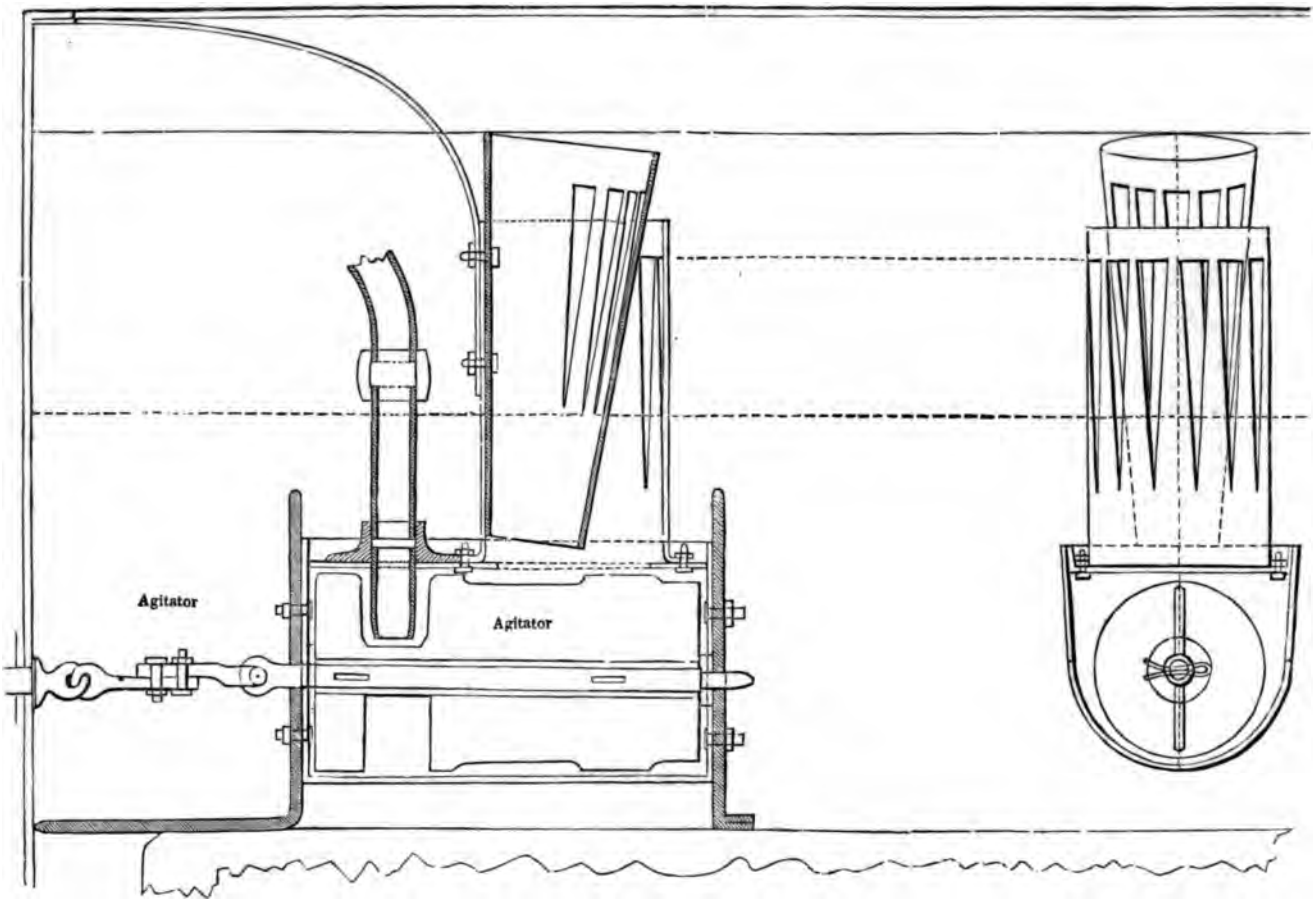
Plan of Collecting Vessel from top.

Fig. 159.



Plan of upper Collecting Vessel.

Fig. 160.



Scale one and half inch=1 foot.

ENLARGED VIEW OF SEDIMENT COLLECTORS; AS APPLIED TO A STEAM VESSEL OF 240 H. P.,
BY R. ARMSTRONG, MANCHESTER.

Longitudinal Section and Elevation of Collectors.

We cannot afford to surrender any more space to these specimens of boilers, and must now proceed to despatch what we have still to say on the subject of boilers in as few words as possible. We have already stated that a cubic foot of water raised into steam is reckoned equivalent to a horse power, and that to generate the steam with sufficient rapidity, an allowance of one square foot of fire bars, and one square yard of effective heating surface, are very commonly made in practice, at least in land engines. These proportions, however, greatly vary in different cases; and in some of the best marine engine boilers, where the area of fire-grate is restricted by the breadth of the vessel, and the impossibility of firing long furnaces effectually at sea, half a square foot of fire-grate per horse power is a very common proportion. Ten cubic feet of water in the boiler per horse power, and ten cubic feet of steam room per horse power, have been assigned as the average proportion of these elements; but the fact is, no general rule can be formed upon the subject, for the proportions which would be suitable for a waggon boiler would be inapplicable to a tubular boiler, whether marine or locomotive; and good examples will in such cases be found a safer guide than rules which must often give a false result. A capacity of three cubic feet per horse power is a common enough proportion of furnace-room, and it is a good plan to make the furnaces of a considerable width, as they can then be fired more effectually, and do not produce so much smoke as if they are made narrow. As regards the question of draft, there is a great difference of opinion among engineers upon the subject, some preferring a very slow draft and others a rapid one. It is obvious that the question of draft is virtually that of the area of fire-grate, or of the quantity of fuel consumed upon a given area of grate surface, and the weight of fuel burned on a foot of fire-grate per hour varies in different cases in practice from 3½ to 80 lbs. Upon the quickness of the draft again hinges the question of the proper thickness of the stratum of incandescent fuel upon the grate; for if the draft be very strong, and the fire at the same time be thin, a great deal of uncombined oxygen will escape up through the fire, and a needless refrigeration of the contents of the flues will be thereby occasioned; whereas, if the fire be thick, and the draft be sluggish, much of the useful effect of the coal will be lost by the formation of carbonic oxide. The length of the circuit made by the smoke varies in almost every boiler, and the same may be said of the area of the flue in its cross section, through which the smoke has to pass. As an average, about one-fifth of the area of fire-grate for the area of the flue behind the bridge, diminished to half that amount for the area of the chimney, has been given as a good proportion, but the examples which we have given, and the average flue area of the boilers which we shall describe, may be taken as a safer guide than any such loose statements. When the flue is too long, or its sectional area is insufficient, the draft becomes insufficient to furnish the requisite quantity of steam; whereas if the flue be too short or too large in its area, a large quantity of the heat escapes up the chimney, and a deposition of soot in the flues also takes place. This last fault is one of material consequence in the case of tubular boilers consuming bituminous coal, though indeed the evil might be remedied by blocking some of the tubes up. The area of water-level we have already stated, p. 48., as being usually about 5 feet per horse power in land boilers. In many cases, however, it is much less; but it is always desirable to make the area of the water-level as large as possible, as when it is contracted not only is the water-level subject to sudden and dangerous fluctuations, but water is almost sure to be carried into the cylinder with the steam, in consequence of the violent agitation of the water, caused by the ascent of a large volume of steam through a small superficies. It would be an improvement in boilers. we think, to place over each furnace an inverted vessel immerged in the water, which might catch the steam in its ascent, and deliver it quietly by a pipe rising above the water-level. The water-level would thus be preserved from any inconvenient agitation, and the weight of water within the boiler would be diminished at the same time that the original depth of water over the furnaces was preserved. It would also be an improvement to make the sides of the furnaces of marine boilers sloping, instead of vertical, as is the common practice, for the steam could then ascend freely at the instant of its formation instead of being entangled among the rivets and landings of the plates, and superinducing an overheating of the plates by preventing a free access of the water to the metal.

In the Transactions of the Institution of Civil Engineers several papers are given by Mr. Parkes and others descriptive of experiments made by them on steam boilers. We have, in Table 1., collected a few of the principal results exhibited in Mr. Parkes' very voluminous tables, and we have added the two columns on the right hand side of the table to show at the same time the evaporative economy of the boilers in use at the East London Water Works. One of these boilers is on the Cornish plan, and attached to the Cornish engine there. The other is a waggon boiler, with an internal flue, for supplying steam to a Boulton and Watt pumping engine. The Cornish boilers are cylindrical, with an internal flue; and, as they are generally used with steam of from 15 lbs. to 35 lbs. above the atmosphere, they are made of plates half an inch thick. The left hand column in the table gives the mean results of experiments made on the boilers at the Huel Towan and United Mines in Cornwall. The second column from the left is devoted to Mr. Parkes' experiments at Warwick; and, according to him, about one sixth of the evaporation there given is due to his smoke-consuming apparatus. The third column exhibits the mean of eight experiments on waggon boilers, at the different places indicated at the head of the column, which were all (except the Albion Mills experiments) conducted by Mr. Parkes. The fourth column from the left contains the results of Mr. Smeaton's experiments on his atmospheric engine at Long Benton; and the fifth column gives the mean of eleven experiments on locomotives by Mr. Pambour. Referring to the sixth line, it will be seen that the mean evaporative economy of the Cornish boilers is about the same as that of the Warwick boilers; but, if we exclude the East London Water Works boiler, the other Cornish boilers will show a decided superiority over all the rest. Lines five and eight show two of the principal peculiarities in the proportions of the Cornish boilers. It will be observed that the extent of their surface exposed to the heat, for each cubic foot of water evaporated, is about seven times as great as in any of the others. The combustion in their furnaces also is carried on at a very slow rate, there being only about 3½ lbs. of coals burned on each square foot of grate. The only boiler that makes any approach to them in slowness of combustion is the one at Warwick. Mr. Parkes is a great advocate for slow combustion; and he founds his opinions principally on its effect in the Warwick boilers—at least it is from his experiments on them that he derives his opinion that the principle should be carried so far as it was in that case. We conceive that in this instance he has overlooked one very material circumstance. It will be observed in the table, that the heated surface bears very nearly the same proportion to the water evaporated in these boilers as in the other waggon boilers; but, before Mr. Parkes altered his furnaces, much more water was evaporated per boiler, and, consequently, the heating surface must then have been very small in proportion to the evaporation. We are, therefore, rather inclined to attribute the increased duty of the fuel to the increase of the heating surface of the boiler than to the diminution of the rate of combustion. Nevertheless, from other experiments of Mr. Parkes, we are disposed to think that, for economy of fuel, the combustion in the generality of waggon boiler furnaces is rather too rapid. The very large proportion that the heating surface in the Cornish boilers bears to the weight of water evaporated is, no doubt, to a considerable extent, rendered necessary by the thickness of the plates which the heat has to penetrate, and the high temperature of the water within them—both circumstances that retard the transmission of the heat. The Cornish practice, too, is universally, so far as we have been able to ascertain, in favour of this great extent of surface; yet we can hardly think that a small diminution of it would produce any injurious effect on the economical properties of the boiler, while it would save a considerable part of the original cost.

It will be seen, from what we have already advanced, that but a small part of the superior duty of the Cornish engines can be derived from the boilers; we must therefore look to the engines for the principal sources of their superiority, which may be comprised under these three heads:—

1st. The use of high-pressure steam cut off when a very small part of the stroke has been performed, and working expansively over the remainder.

2nd. The careful clothing of every part of the engine where heat can escape. The cylinder is usually encased with a steam-jacket; and the steam-jacket itself, and all the steam-pipes, top of the boiler, &c., are protected from the cold air by being covered with a layer of three or four inches thick of ashes, saw-dust, or other good non-conductor of heat. The amount of saving effected in this way may be conceived to be very considerable. We have not met with any experiments to ascertain the amount of the saving by clothing the whole engine; but Mr. Wicksteed found that clothing the top of the boilers *alone* produced a saving of 10¼ per cent. in the fuel consumed.

3rd. The third main source of the great duty of the Cornish engines is to be found in the excellent system of registering and publishing the duty of each engine, which has for many years been prevalent in Cornwall. It has made both the proprietors and engineers much more careful than they otherwise would have been of a host of details that have elsewhere been considered too trifling to require notice; but which, nevertheless, in the aggregate, are of no small importance.

TABLE I.	Mean of Huel Towan, and United Mines boilers, in Cornwall.	Mr. Parkes' boiler, at Warwick.	Mean of 8 experiments at the Albion Mills, Clithero, Preston, and New River Water Company, of London.	Smeaton's Atmospheric Engine, at Long Benton, Northumberland, 1772.	Mean of 11 of M. Pambour's experiments on the Locomotives of the Liverpool and Manchester Railway.	Cornish boiler at the East London Water Works, 1839.	Boulton and Watt boiler at the East London Water Works, 1839
NATURE OF THE BOILERS USED.	Cylindrical with internal flue.	Waggon.	Waggon.	Circular or Hay-stack.	Locomotive.	Cylindrical with internal flue.	Waggon with internal flue.
Total area of heated surface in square feet .	969	152	342·8	459	334·6	798	588
Length of circuit made by the heat in feet .	155	50·66	72·5	52·8	7·0	83·1	78
Area of fire grates in square feet . . .	23·66	23·33	26·09	35·10	7·03	14·25	37·26
Weight of fuel burned on each square foot of grate, per hour, in lbs.	3·46	4·00	10·75	20·34	79·33	46·82	13·31
Cub. ft. of water evaporated from initial temperature by 112 lbs. of fuel	18·87	16·44	13·91	14·11	11·14		
Cubic feet of water evaporated per hour from initial temperature	13·81	13·79	34·40	90·7	55·18		
Square feet of heated surface for each cubic foot of water evaporated per hour . .	69·58	11·00	9·96	5·06	6·06	17·17	
Square feet of heated surface for each square foot of grate . . .	40·65	6·51	13·13	13·08	47·59	56·0	15·78
Pressure of steam above the atmosphere in lbs.	42·2	2·5	3·68	1·5	50	15·45	
Kind of coal used * . .	W.	S.	L. & N.	N.	Coke.	N.	N.

* W. Welsh.—S. Staffordshire.—L. Lancashire.—N. Newcastle.

The grand secret, however, of the economy of the Cornish engines lies in the large application of the principle of expansion, and the results there obtained are very little aided by any peculiar excellence in the boiler. Upon the merits of expansion, however, or the pitch to which it may be beneficially carried in particular cases, this is not the place to enlarge, but we may here give a table from the *Artizan*, which shows the relative efficacy of different engines with different degrees of expansion.

The first column on the left exhibits the performance of Smeaton's atmo-

TABLE II.	Smeaton's Atmospheric Engine, Long Benton, Northumberland, date 1772.	Boulton and Watt's non-expansive rotative condensing Engine, Albion Mills, London, date 1786.	Holmbush, Cornish, condensing Engine, single acting for pumping water. Steam acts expansively after the first sixth of the stroke. 1836.	Noncondensing double-acting Engine, nonexpansive, Congleton, Cheshire. 1823.	Cornish Engine. East London Water Works.	Boulton and Watt's pumping Engine at East London Water Works.
Diameter of cylinder in inches - - - - -	52	34	50	13	79¾	59⅝
Length of stroke in feet - - - - - -	7	8	9·1	4	10	7·91
Number of strokes per minute - - - - -	12	16	4·63	27·5	7	11·5
Pressure on the piston, above or below the atmosphere in lbs., per square inch - - - - - -	....	Estimated at —2·5	+ 30	+ 20	+ 5·17	+ 2·15
Weight in lbs. raised one foot by 112 lbs. of coals - -	12,600,000	25,756,752	140,484,848	12,418,560	105,664,118	46,602,333
Do. do. by one pound of water, as steam	14,280	28,489	119,097	15,840	110,716	53,369
Effective power of the engine at time of experiment in horse power - - - - - - -	40·5	50·0	26·48	12·0	. . . .	
Efficiency of the steam, its efficiency in the Albion Mills being unity - - - - - - -	·501	1·000	4·180	·556	3·89	1·87
Efficiency of the fuel, its efficiency in the Albion Mills being unity - - - - - - -	·480	1·000	5·454	·482	4·1	1·81
Distance of the piston from the end of its stroke when the steam is cut off in parts of the length of stroke -	0	0	·833	0	·687	·5

spheric engine at Long Benton. In the second column will be found similar particulars of Boulton and Watt's condensing rotative engine at the Albion Mills. In the third column we have put down the same data for the Holmbush Cornish engine; and, in the fourth, for a high-pressure non-condensing engine, whose duty was determined by Mr. Wicksteed. The last two columns supply the same data for a Cornish engine and Boulton and Watt pumping-engine, at the East London Water Works. The economical effects of expansion will be found to be very clearly exhibited in this table. The duties are recorded in the fifth line from the top, and the degree of expansion in the bottom line. It will be observed, that the order in which the different engines stand in respect of superiority of duty is the same as in respect of amount of expansion. The Holmbush engine has a duty of 140,484,848 lbs. raised 1 foot by 1 cwt. of coals, and the steam acts expansively over ·830 of the whole stroke; while the water-works' Cornish engine has only a duty of 105,664,118 lbs., and expands the steam over only ·687 of the whole stroke. Again, comparing the two Boulton and Watt engines together, the Albion Mills engine has a duty of 25,756,752 lbs., and no expansive action. The water-works' Boulton and Watt engine, again, acts expansively over one-half of its stroke, and has an increased duty of 4,660,333 lbs. Other causes, of course, may influence these comparisons, especially the last, where one engine is a double-acting rotative engine, and the other a single-acting pumping one; but there can be no doubt that the expansive action in the latter is the *principal* cause of its more economical performance.

The heating surface per horse power allowed by Boulton and Watt is about 9 square feet in waggon boilers, reckoning the total surface as effective surface, if the boilers be of a considerable size; but in the case of small boilers, the proportion is larger. The total heating surface of a two horse power waggon boiler is, according to Boulton and Watt's proportions, 30 square feet, or 15 ft. per horse power; whereas, in the case of a 45 horse power boiler the total heating surface is 438 square feet, or 9·6 ft. per horse power. The capacity of steam room is 8¾ cubic feet per horse power, in the two horse power boiler, and 5¾ cubic feet in the 20 horse power boiler; and in the larger class of boilers, such as those suitable for 30 and 45 horse power engines, the capacity of the steam room does not fall below this amount, and indeed is nearer 6 than 5¾ cubic feet per horse power. The content of water is 18¼ cubic feet per horse power in the two horse power boiler, and 15 cubic feet per horse power in the 20 horse power boiler. In marine boilers about the same proportions obtain in most particulars. The original boilers of the "Great Western" steamer, by Messrs. Maudslay, figured in page 62, were proportioned with about half a square foot of fire grate per horse power, and 10 square feet of flue and furnace surface, reckoning the total amount as effective; but in the boilers of the "Retribution," by the same makers, shown in page 76, a somewhat smaller proportion of heating surface was adopted. Boulton and Watt have found that in their marine flue boilers 9 square feet of flue and furnace surface are requisite to boil off a cubic foot of water per hour, which is the proportion that obtains in their land boilers; but inasmuch as in modern engines the nominal considerably exceeds the actual power, they allow 11 square feet of heating surface per nominal horse power in their marine boilers, and they reckon as effective heating surface, the tops of the flues, and the whole of the sides of the flues, but not the bottoms. They have been in the habit of allowing for the capacity of the steam space in marine boilers 16 times the content of the cylinder; but as there are two cylinders this is equivalent to 8 times the content of both cylinders, which is the proportion commonly followed in land engines, and which agrees very nearly with the proportion of between 5 and 6 cubic feet of steam room per horse power. Taking, for example, an engine with 23 inches diameter of cylinder and 4 feet stroke, which will be 18·4 horse power—the area of the cylinder will be 415·476 square inches, which multiplied by 48, the number of inches in the stroke, will give 19942·848 for the capacity of the cylinder in cubic inches; 8 times this is 159542·784 cubic inches, or 92·3 cubic feet; 92·3 divided by 18·4 is rather more than 5 cubic feet per horse power. There is less necessity, however, that the steam space should be large when the flow of steam from the boiler is very uniform, as it will be where there are two engines attached to the boiler at right angles with one another, or where the engines work at a great speed, as in the case of locomotive engines. A high steam chest too, by rendering boiling over into the steam pipes, or priming as it is called, more difficult, obviates the necessity for so large a steam space; and the use of steam of a high pressure, worked expansively, has the same operation; so that in modern marine boilers, of the tubular construction, where the whole of these modifying circumstances exist, there is no necessity for so large a proportion of steam room as 5 or 6 cubic feet per horse power, and about half that amount more nearly represents the general practice. Boulton and Watt allow 0·64 of a square foot per nominal horse power of grate bars in their marine boilers, and a good effect arises from this proportion; but sometimes so large an area of fire grate cannot be conveniently got, and the proportion of half a square foot per horse power seems to answer very well in engines working with some expansion, and is now very widely adopted. With this allowance, there will be about 22 square feet of heating surface per square foot of fire grate, and if the consumption of fuel be taken at 6 lbs. per nominal horse power per hour there will be 12 lbs. of coal consumed per hour on each square foot of grate. The flues of all flue boilers diminish in their calorimeter as they approach the chimney: some very satisfactory boilers have been made by allowing a proportion of 0·6 of a square foot of fire grate per nominal horse power, and making the sectional area of the flue at the largest part $\frac{1}{7}$th of the area of fire grate, and the smallest part where it enters the chimney $\frac{1}{11}$th of the area of the fire grate; but in some of the boilers proportioned on this plan the maximum sectional area is only $\frac{1}{7\cdot3}$ or $\frac{1}{8\cdot3}$, according to the purposes of the boiler. These proportions are retained whether the boiler is flue or tubular, and from 14 to 16 square feet of tube surface is allowed per nominal horse power; but such boilers, although they may give abundance of steam, are generally, perhaps needlessly, bulky.

We must now, however, dimiss these speculations, and with them the whole subject of the efficacy of different kinds of boilers, upon which we have already expatiated sufficiently: we shall therefore conclude our remarks upon the subject by introducing a table of the comparative evaporative power of different kinds of coal, which we have derived from Mr. Wicksteed's experiments, and which will prove useful, by affording data for the comparison of experiments upon different boilers when different kinds of coal are used. Without this means of reduction, experiments would be useless for comparison, unless the fuel employed was in every case of equal evaporative power; but when the relation between the evaporative power of different kinds of coals is ascertained, the results of experiments can be easily reduced so as to render them comparable with one another.

Table of the Comparative Evaporative Power of different kinds of Coal.

No.	Description of Coals.	Water evaporated per lb. of Coals.	Value per Ton in the Pool.
		Lbs.	*s. d.*
1	The best Welsh - - - - -	9·493	17 11
2	Anthracite - - - - - -	9·014	17 0
3	The best small Newcastle - - -	8·524	16 1
4	Average small Newcastle - - -	8·074	15 2¾
5	Average Welsh - - - -	8·045	15 2¼
6	Coke from Gas-works - - -	7·908	14 11
7	Coke and Newcastle, small, ½ and ½ -	7·897	14 10¾
8	Welsh and Newcastle, mixed ½ and ½ -	7·865	14 10
9	Derbyshire and small Newcastle, ½ & ½	7·710	14 6½
10	Average large Newcastle - - -	7·658	14 5½
11	Derbyshire - - - - - -	6·772	12 9¼
12	Blythe Main, Northumberland - -	6·600	12 5¼

Strength of boilers. The extension of the expansive method of employing steam to boilers of every denomination, and the gradual introduction in connection therewith of a higher pressure than formerly, makes the question of the strength of boilers one of great and increasing importance. This topic was very successfully elucidated a few years ago by a committee of the Franklin Institute, and we shall here recapitulate a few of the more important of the conclusions at which they arrived. Iron boiler plate was found to increase in tenacity as its temperature was raised until it reached a temperature of 550° above the freezing point, at which point its tenacity began to diminish. The following table exhibits the cohesive strength at different temperatures.

At 32° to 80° the tenacity was = 56,000 lbs., or 1-7th below its maximum.
At 570° —— = 66,500 lbs., the maximum.
At 720° —— = 55,000 lbs., the same nearly as at 32°.
At 1050° —— = 32,000 lbs., nearly ½ of the maximum.
At 1240° —— = 22,000 lbs., nearly ⅓ of the maximum.
At 1317° —— = 9,000 lbs., nearly 1-7th of the maximum.
At 3000° iron becomes fluid.

The difference in strength between strips of iron cut in the direction of the fibre, and strips cut across the grain, was found to be about 6 per cent. in favour of the former. Repeated piling and welding was found to increase the tenacity and closeness of the iron, but welding together different kinds of iron was found to give an unfavourable result; rivetting plates was found to occasion a diminution in their strength, to the extent of about one-third. The accidental overheating of a boiler was found to reduce its strength from 65,000 lbs. to 45,000 lbs. per square inch. Taking into account all these contingencies, it appears expedient to limit the tensile force upon boilers in actual use to about 3000 lbs. per square inch of iron.

Copper follows a different law, and appears to diminish in strength by every addition of heat, reckoning from the freezing point. The square of the diminution of strength seems to keep pace with the cube of the temperature, as appears by the following table:—

Table showing the Diminution of Strength of COPPER *Boiler Plates by additions to the Temperature. the Cohesion at 32° being 32,800 lbs. per Square Inch.*

No.	Temperature above 32°.	Diminution of Strength.	No.	Temperature above 32°.	Diminution of Strength.
1	90°	0·0175	9	660°	0·3425
2	180	0·0540	10	769	0·4398
3	270	0·0926	11	812	0·4944
4	360	0·1513	12	880	0·5581
5	450	0·2046	13	984	0·6691
6	460	0·2133	14	1000	0·6741
7	513	0·2446	15	1200	0·8861
8	529	0·2558	16	1300	1·0000

In the case of iron, the following are the results when tabulated after a similar fashion.

Table of Experiments on Iron *Boiler-Plate at High Temperatures; the Mean Maximum Tenacity being at* 550° = 65,000 *lbs. per Square Inch.*

Temperature observed.	Diminution of Tenacity observed.	Temperature observed.	Diminution of Tenacity observed.
550°	0·0000	824°	0·2010
570	0·0869	932	0·3324
596	0·0899	947	0·3593
600	0·0964	1030	0·4478
630	0·1047	1111	0·5514
562	0·1155	1155	0·6000
722	0·1436	1159	0·6011
732	0·1491	1187	0·6352
734	0·1535	1237	0·6622
766	0·1589	1245	0·6715
770	0·1627	1317	0·7001

The application of stays to marine boilers, especially in those parts of the water spaces which lie in the wake of the furnace bars, has given engineers much trouble; the ⅜ plate, of which ordinary boilers are composed, is hardly thick enough to retain a stay with security by merely tapping the plate, whereas, if the stay be rivetted, the head of the rivet will in all probability be soon burnt away. The best practice appears to be to run the stays used for the water spaces in this situation, in a line somewhat beneath the level of the bars, so that they may be shielded as much as possible from the fire, while those which are required above the level of the bars should be kept as nearly as possible towards the crown of the furnace, so as to be removed from the immediate contact of the fire. Screw bolts with a fine thread tapped into the plate, and with a thin head upon the one side, and a thin nut made of a piece of boiler plate on the other, appear to be the best description of stay that has yet been contrived. The stays between the sides of the boiler shell, or the bottom of the boiler and the top, present little difficulty in their application, and the chief thing that is to be attended to is to take care that there be plenty of them; but we may here remark that we think it an indispensable thing, when there is any high pressure of steam to be employed, that the furnace crown be stayed to the top of the boiler. This it will be observed is done in the boilers of the Tagus and Infernal, constructed by Messrs. Miller, Ravenhill, and Co., and figured at pages 66. 71. and 72; and we know of no better specimen of staying than is afforded by those boilers.

Explosions.—This subject has been investigated with much care by the committee of the Franklin Institute, whose experiments on the strength of boilers we have already mentioned with commendation. We are unable, however, to follow these experimentalists in their researches, and have only room to remark that we believe most explosions will be found to have arisen either from an undue pressure of the steam, or from the overheating of the plates composing the boiler. The plates of the boiler may become overheated either in consequence of a want of water in the boiler, or from such a configuration of the internal parts of the boiler that the steam when formed cannot escape freely to the surface. The bottoms of large flues upon which the flame beats down are very liable to injury from this cause; and the iron in such a case will probably be softened by the heat, and in all probability will collapse upwards. Lightning, the sudden disengagement of large portions of scale, and other similar accidents have, we believe, caused explosions sometimes. But these causes are of very unfrequent occurrence in comparison with those that we have indicated, and which would be oftener recognised as the real causes of explosions, were it not that people think they show their cleverness best by clearing up a difficulty with a new hypothesis that has been coined for the purpose in fancy's mint.

The plugs of fusible metal sometimes introduced into boilers to obviate explosions by melting out before the steam can reach any high temperature, are found in practice to be of but little avail. The compound metal is not homogeneous, and the more fusible of the metals is melted first, and is forced by the pressure of the steam out of the interstices of the less fusible metal, leaving its place to be supplied by the debris which all water supplies. The consequence is that the plug ceases to be fusible metal of the kind originally introduced, and cannot be melted by the steam even at a pressure and temperature much above that fixed as the requisite fusing point. Plugs of fusible metal should, therefore, we think, be discarded, as they are only calculated to mislead by pretending to do what they cannot accomplish. In tubular boilers, however, it is, we think, a good plan to introduce lead plugs in the tops of the fire-boxes—not with the idea that they will be melted by the steam where its pressure gets high, but to be melted out, and give notice of danger should the water fall too low.

Every boiler should be furnished with a steam gauge, which may give indication of danger should the pressure bocome too great, and the passages leading to the safety-valves should have no connection with the pipes leading to the stop-valves. In some cases stop-valves have been lifted from their seats, and forced into the mouth of the pipe, so that no steam could escape thereby; and in consequence of the safety-valve pipe springing from the pipe connecting the boilers, the boiler thus blocked up was in great danger of bursting, and would have burst if the fires had not been immediately drawn. In the case of any derangement of the safety-valve, or of the cone in the waste steam-pipe of a steam-vessel getting loose, and blocking up the mouth of the pipe, the pressure in the boiler may be eased by opening the blow-through valves of the engines, and the steam gauge will in all cases tell whether any undue pressure exists.

Incrustation.—The incrustation of boilers by saline deposits was a much more important subject at one time than it is now, as nothing has been more clearly established, of late years, than that boilers may be preserved effectually from any injurious incrustation by abundant blowing off. Brine pumps are now in extensive use for withdrawing a certain quantity of water at every stroke of the engine; and the water so withdrawn has to pass through or among pipes carrying the feed-water to the boiler, so that some interchange of heat is there effected. These refrigerators, however, as they are grotesquely called, are in some respects bad things: the quantity of heat they save is, we believe, inappreciable; and the small pipes of which they are built up are liable to get choked, thereby endangering the boiler by the unconscious concentration of its contents. To guard against this danger, every engine fitted with brine pumps should be provided with a hydrometer for telling the specific gravity of the water in the boiler, so that the engineer may not be cheated by the defective action of the pumps, or suppose that they are operating when they are really inert. In the case of blowing out a boiler in the usual way, the engineer looks at his glass gauge tube, and keeps the blow-off cock open until the water-level has descended through the required distance, so that, under these circumstances, no doubt can arise that the boiler has been emptied of a certain quantity of water; but there is no such assurance in the case of the continuous extraction of the water, either by brine pumps or by a continuous blow off; and all boilers using either of these expedients should be fitted with hydrometer gauges as a precaution against the contents of the boiler being suffered to reach an injurious concentration. Numerous prescriptions have at various times been given as antidotes to incrustation; such as putting potatoes and other vegetable matters in the boiler, or, in the case of a steam vessel, taking the feed-water from the bilge. The application of oil to the flues has also been recommended; and some boilers are fitted with a contrivance to inject oil into them just before the steam is let down. We look upon all such expedients, however, as needless, and are confident that boilers require no other preservation from incrustation than effectual blowing off. Collecting vessels, however, are advantageous, as they enable a less amount of blowing off to suffice; and, in the case of the feed supplied to the boiler being muddy water, they conduce to convenience and save fuel by obviating priming. The prevailing fault among engineers, however, is that they do not blow off enough, the idea probably being that a considerable check is given to the generation of the steam by the introduction of colder water in lieu of the water abstracted; but the waste of heat by effectual blowing off is very inconsiderable—much less, indeed, than is occasioned by the difficulty of getting steam from brine, or of transmitting heat to the water through flues covered with incrustation, much of which heat, in consequence, ascends the chimney. There is no gain, therefore, in any respect, by penuriousness in blowing off; and there is much injury to the boiler, for incrusted plates become overheated; they blister, crack, and get burned out, and make expensive repairs indispensable. Proprietors of engines should accept of *no excuse* for the accumulation of salt or incrustation within their boilers; for such deposits arise altogether from insufficient blowing off.

The best method of scaling boilers appears to be by lighting a train of shavings in the furnaces and flues after the boilers have been emptied of water. The rapid expansion of the metal, thus occasioned, causes the scale to crack off; and, if the flues be then washed down with a hose, the scale will fall to the bottom of the boiler, and will issue out with the water on taking off the mud-hole doors. This plan of scaling, however, is one that the engineer must execute himself, and must not entrust to firemen or other subordinates, as the metal of the boiler might be damaged if the heat were made too great. The safety valve should, obviously, be kept open while the boiler is being heated and cooled, to obviate any pressure or exhaustion within it. This plan of scaling, however, will seldom be necessary if due attention be paid to blowing off by the engineer; and if the quantity of scale be inconsiderable, or partial, in its attachment, the best plan will be to chip it off with a hatchet-faced hammer, and then wash down the flues with the hose, as before described.

Corrosion.—The corrosion of boilers is one of the most obscure subjects in the whole range of engineering. Marine boilers seldom last more than four or five years, whereas land boilers, made of the same quality of iron, often last eighteen or twenty years; yet the difference in durability is not the effect of any chemical action upon the iron by the contact of sea water, for the flues of marine boilers rarely show any deterioration from this cause, and, even in worn-out marine boilers, the hammer-marks on the flues are as conspicuous as at the time of their formation. The thin film of scale spread over the internal parts of the boiler would, of itself, preserve that part of the iron from corrosion which is situated below the water level; but, whatever be the cause, it is a rare thing to find any internal corrosion of a boiler using salt water in those parts of the boiler with which the water comes in contact. The cause, therefore, of the rapid wearing out of marine boilers is not traceable to the chemical action of salt water, and steamers provided with Hall's condensers, which supply the boilers with fresh water, have not reaped much benefit in the durability of their boilers. The operation of the steam in corroding the interior of the boiler is most capricious — the parts which are most rapidly worn away in one boiler being untouched in another, and in some cases one side of a steam chest will be very much wasted away while the opposite side remains uninjured. Sometimes the iron exfoliates in the shape of a black oxide which comes away in flakes like the leaves of a book, while in other cases the iron appears as if eaten away by a strong acid which had a solvent action upon it. The application of felt to the outside of a boiler, has in several cases been found to accelerate sensibly its internal corrosion. Boilers in which there is a large accumulation of scale appear to be more corroded than where there is no such deposit, and where the funnel passes through the steam chest the iron of the steam chest is invariably much more corroded than where the funnel does not pass through it. These facts appear to indicate that the internal corrosion of marine boilers is attributable chiefly to the existence of surcharged steam within them, which is steam to which an additional quantity of heat has been communicated subsequently to its generation, so that its temperature is greater than is due to its elastic force; and on this hypothesis the observed facts relative to corrosion become easily explicable. Felt applied to the outside of a boiler may accelerate its internal corrosion by keeping the steam in a surcharged state, when by the dispersion of a part of the heat it would cease to be in that state. Boilers in which there is a large accumulation of scale must have worked with the water very salt, which necessarily produces surcharged steam; for the temperature of steam cannot be less than that of the water from which it is generated, and inasmuch as the boiling point of water, under any given pressure, rises with the saltness of the water, the temperature of the steam must rise with the saltness of the water, the pressure remaining the same; or in other words the steam must have a higher temperature than is due to its elastic force, or be in the state of surcharged steam. The circumstance of the chimney flue passing through the steam will manifestly surcharge the steam with heat, so that all the circumstances which are found to accelerate corrosion are, it appears, such as would also induce the formation of surcharged steam. Besides, the natural effect of surcharged steam is to oxidate the iron with which it is in contact, as is illustrated by the familiar process for making hydrogen gas by sending steam through a red-hot tube filled with pieces of iron; and although the action of the surcharged steam in a boiler is necessarily very much weaker than where the iron is red-hot, it manifestly must have *some* oxidising effect, and the amount of corrosion produced may be very material where the action is perpetual. Boilers with a large extent of heating surface, or with descending flues circulating through the cooler water in the bottom of the boiler before ascending the chimney, will be less corroded internally than boilers in which a large quantity of the heat passes away in the smoke. If these views be correct, then to prevent the internal corrosion of marine boilers it is only necessary to take care that the water in the boiler shall be as fresh as possible, and that the root of the chimney shall either be lined with fire brick, or not go through the steam at all.

Area of Steam Passages.

Any excess in size of the connecting pipes which convey the steam to the cylinder is of little consequence in the construction of the steam engine, otherwise than by the effect that it may produce in diminishing the temperature of the steam, an effect that we will have occasion to consider by and bye; for until the steam has got beyond the narrowest part of the passages, it must be of the same density as it is in the boiler, but on entering the cylinder it must dilate itself until the density is so far reduced as to cause the difference of pressure which produces the increase of velocity through the contracted apertures; and since the elastic force is proportional to the density, the condition of equilibrium obtains when the elastic force of the steam in the boiler, drawn into its velocity through the apertures and the area of the apertures, is equal to the elastic force of the steam in the cylinder drawn into the area of the piston and the velocity of its motion; and from the equation of equilibrium here enunciated, the area of the steam passages or apertures can readily be ascertained; but for the purpose of expressing the relation generally,

Put f = the elastic force of the steam in the boiler, in inches of mercury, corresponding to any given temperature,
f' = the elastic force of the steam in the cylinder, in inches of mercury, when reduced by expansion,
a = the area of the steam passages or apertures in square inches,
v = the velocity with which the steam from the boiler passes through the apertures in feet per second,
a' = the area of the piston in square inches, and
v' = the velocity of its motion in feet per second,

Therefore, by employing these symbols in the equation of condition as verbally expressed above, the momentum or mechanical effect of the steam in the boiler, when referred to its motion through the apertures, is expressed by the term $f\,a\,v$, and the momentum or mechanical effect of the steam in the cylinder after passing the apertures, when referred to the motion of the piston, is expressed by the term $f'a'v'$; but in the case of an equilibrium between the forces, these terms must be equal in value; let them therefore be compared with one another, and the equation in general terms becomes $f\,a\,v = f'\,a'\,v'$; this is the *equation of condition* that must always be satisfied when an equilibrium obtains, and from it an expression for the value of v, or the velocity with which the steam passes the apertures can easily be deduced.

At page 43. it is stated that when a passage is opened between two vessels containing fluids of different densities, the fluid of greatest density rushes out of the vessel that contains it into the one containing the rarer fluid with a velocity equal to that acquired by a heavy body in falling through the difference between the heights of two uniform columns of the fluid of greatest density, competent to produce the pressures under which the fluids are respectively confined. Now, the principle here enunciated is precisely that which applies to steam in the boiler under its full intensity of pressure, and the same steam when transmitted to the cylinder under its diminished pressure.

In order to discuss the principle analytically, which is the best and easiest way in the present instance, let the symbol h denote the height of the uniform column corresponding to the pressure in the boiler, and h' the height of a column of the same density corresponding to the pressure in the cylinder; then is $(h-h')$ the height of the column which produces the velocity through the apertures; that is, the velocity with which the steam enters the cylinder; therefore, by putting $(h-h')$ for h in No. 12. of the class of formulæ given at page 43, the expression for the velocity in question becomes $10\,v = \sqrt{4225\,(h-h')}$, or $v = 6{\cdot}5\,\sqrt{(h-h')}$; consequently, by transferring this value of v to the general equation of condition, we get $6{\cdot}5\,f\,a\sqrt{(h-h')} = f'a'v'$. But according to what has been shown at page 44, the height of a column producing the velocity is equal to 1·1341 times the elastic force of the steam multiplied by its volume from a cubic foot of water, or, rather, by the number of times that the volume of steam exceeds that of the water from which it is generated. In the present instance, however, the force to be considered must be the difference between the forces in the boiler and the cylinder; that is $(f-f')$; therefore, if b denote the bulk of the steam from an unit of water, the principle that we have just announced gives $(h-h') = 1{\cdot}1341\,b\,(f-f')$; hence we have $6{\cdot}922\,f\,a\sqrt{b\,(f-f')} = f'a'v'$.

Let the symbol b, which has just been introduced into the expression, be replaced by its equivalent value in equation (U) page 42., and let n be the fraction that indicates the loss or diminution of force that takes in the steam, on being transmitted from the boiler to the cylinder; then we have $b = \frac{75{\cdot}67(\text{temp.} + 459,}{f}$, and $nf = (f-f')$; therefore, by substituting these values in the expression immediately above, we obtain after a little reduction, the following modified expression, viz.

$$60{\cdot}2143\ fa\sqrt{n\ (\text{temp.} + 459)} = f'a'v'.$$

From this equation, any one of the quantities which it involves can readily be determined in terms of the rest; but in order to adapt it for practical application, we must eliminate the quantities f and f', which indicate the elastic forces of the steam in the boiler and the cylinder respectively, and this we are enabled to do by means of the expression $nf = f - f'$, for by transposition we have $f = f' - nf$, and by collecting the terms, it is $f\,(1-n) = f'$; therefore, by substitution, we get

$$60{\cdot}2143\ a\sqrt{n\,(\text{temp.} + 459)} = a'v'\ (1-n).$$

The equation in its present form indicates an equilibrium when the motion is made through a pipe of uniform diameter, without bends or obstructions of any kind otherwise than what takes place at the apertures; but in order to make allowance for such causes of retardation in the velocity as usually occur in well-constructed and judiciously arranged engines, we must reduce the co-efficient from 60·2143 to 41·6868, according to a notice at page 44., and then we have

$$41{\cdot}6868\ a\sqrt{n\,(\text{temp.} + 459)} = a'v'\ (1-n).$$

If there were any direct means of determining the value of n in this equation, the area of the passages corresponding to any given temperature or elastic force in the boiler could be found in all cases by a very simple process; but since there is no maximum limit to the expression, the proportion of the power that is lost in producing the velocity can only be approximated by combining the results of numerous observations on the performance of good engines. The general practice of eminent manufacturers is to make the area of the steam passages about two tenths of the area of the piston. Messrs. Boulton and Watt adopted this proportion in their best engines; but other makers consider that one square inch of passage for each horse power is a good proportion, and this they adhere to without assigning any reason for their choice: it is, however, evident that the intention of both these maxims is to give the steam the same velocity through the passages in engines of all sizes; but this cannot be correct, if the principle be admitted, that the horse power in small engines requires more steam than it does in large ones, and this is a point that we believe few persons will feel inclined to dispute, though the influence of such a truth upon the size of the steam passages cannot be material in practice.

Since it is the practice of engineers, when discussing the properties of engines, to estimate their peformances by the diameter of the cylinder, the length of stroke, and the number of strokes per minute, it may be proper, before we proceed, to apply our formula to the determination of the area of the steam passages, so to modify it, as to involve the terms peculiar to practical men; and for this purpose

Let d = the diameter of the piston estimated in inches;
δ = the diameter of the steam passages, estimated also in inches;
l = the length of the stroke in feet; and
n' = the number of strokes per minute.

Then we have $30\,v' = ln'$, or $v' = \frac{1}{30}ln'$, and by the principles of mensuration it is $a : a' :: \delta^2 : d^2$; consequently by substitution we have,

$$1250{\cdot}604\,\delta^2\sqrt{n\,(\text{temp.}+459)} = d^2\,ln'\,(1-n).$$

We are now approaching the ultimate practical form of the equation; but we have still to assume a value to the quantity n. Tredgold makes it $\frac{1}{142}$th of the force of steam in the boiler; and from his well-known attention to accuracy, we adopt it as being probably very near the truth; at all events, we are not aware that subsequent researches have elicited a standard that agrees more nearly with observation. From this value of n we get, by taking the nearest unit in the coefficient,

$$105\,\delta^2\sqrt{(\text{temp.}+459)} = d^2ln'.$$

Having thus obtained the final form of the equation of condition, we have next to determine from it the diameter of the steam pipe, or rather, the diameter of the orifice through which the steam enters the cylinder; and for this purpose we have only to divide both sides of the expression by all the quantities with which the required quantity is combined, and this being done, we get,

$$\delta^2 = \frac{d^2ln'}{105\sqrt{(\text{temp.}+459)}};$$

this expression, however, involves the square of the required quantity; and therefore, in order to determine its simple value, we must extract the square root of both terms; and thus we obtain

$$\delta = d\sqrt{ln'} \div \sqrt[4]{11025\,(\text{temp.}+459)} \qquad (a).$$

Since the fourth root has to be extracted from the denominator of the fraction in our equation, it would be difficult to represent it in a specific form; but the method of reducing it may be expressed in words as follows:—

Rule. *To the temperature of steam in the boiler add the constant increment 459; multiply the sum by 11025; and extract the square root of the product. Multiply the length of stroke by the number of strokes per minute; divide the product by the square root just found; and multiply the square root of the quotient by the diameter of the cylinder; the product will be the diameter of the steam passages.*

Example. Let it be required to determine the diameter of the steam passages in an engine of which the diameter of the cylinder is 48 inches, the length of stroke 4½ feet, and the number of strokes per minute 26, supposing the temperature under which the steam is generated to be 250 degrees of Fahrenheit's thermometer.

Here by the rule we get $\sqrt{11025\,(250+459)} = 2795{\cdot}84$; the number of strokes is 26, and the length of stroke 4½ feet; hence it is $\delta = d\sqrt{\frac{117}{2795{\cdot}84}} = 0{\cdot}20456d = 0{\cdot}20456 \times 48 = 9{\cdot}819$ inches; so that the diameter of the steam passages is a little more than one-fifth of the diameter of the cylinder. The same rule will answer for high and low pressure engines, and also for the passages into the condenser.

LOSS OF FORCE BY THE DECREASE OF TEMPERATURE IN THE STEAM PIPES.

It has already been mentioned that largeness in the steam pipes between the boiler and the narrowest part of the passages, or where the steam enters the cylinder, is of no importance whatever as regards the power of the engine, otherwise than by its effect in diminishing the temperature of the steam, in consequence of the quantity of surface exposed to the cooling influence of the atmosphere. In modern practice this effect is greatly reduced, by covering the steam pipes with felt or some other substance of a like nature, which serves to retain the heat and prevent the external air from coming into contact with the metal surface; but, admitting the pipes to be employed in their naked state, it may be useful to inquire what may be the probable amount of loss arising from the diminution that takes place in the temperature of the steam during its progress from the boiler to the cylinder.

Put d = the diameter of the steam pipe estimated in inches, being the usual measure of that dimension;
l = the length of steam pipe, or the distance between the boiler and the cylinder in feet, including bends, &c.;
v = the velocity of the steam in moving along the passages, estimated in feet per second;
t = the temperature of the surface of the steam pipe; and
t' = the temperature of the external air, which in its mean state may be taken at 60° of Fahrenheit.

Then, by the rules of mensuration, the area of the transverse section of the steam pipes is expressed by the term $\frac{1}{4}\pi d^2$, where the symbol π denotes the periphery of a circle whose diameter is unity; that is, $\pi = 3{\cdot}1416$. But the quantity of steam that passes through the pipes in one second is equal to the area of the section multiplied by the velocity of motion; consequently, the quantity passing is expressed by the term $\frac{1}{4}\pi d^2v$; or, in cubic feet, it is $\frac{\pi d^2v}{576}$. Again, the surface of the steam pipe is equal to the circumference of the transverse section multiplied by its length; hence, the surface in square feet is expressed by the term $\frac{\pi dl}{12}$; but, by the laws of cooling, the loss of heat is directly proportional to the surface of the pipes, and inversely as the quantity exposed in a second; consequently, the loss of heat in one second of time, that is, the loss of heat experienced by the quantity of steam that passes through the pipes in one second, is proportional to $\frac{\pi dl}{12} \times \frac{576}{\pi d^2v} = \frac{48l}{dv}$. Mr. Tredgold, in his treatise on "Warming and Ventilating," has shown that, in the case of cast-iron pipes, the quantity of heat abstracted in a minute by an unit of pipe is expressed by $2{\cdot}1\ (t-t')$; therefore, if t'' be put to denote the loss of heat in one second, we shall, by combining the above terms, obtain the following equation, viz.

$$dvt'' = 1{\cdot}68l\,(t-t');$$

and, by reducing this expression in reference to t'', it becomes

$$t'' = \frac{1{\cdot}68l\,(t-t')}{dv} \qquad (b).$$

Here we have a very simple expression for determining the loss of heat or the diminution of temperature that takes place in the steam during its passage from the boiler to the cylinder; and the method of reducing it may be expressed in words at length as follows:

Rule. *From the temperature of the surface of the steam pipes* subtract the temperature of the external air; multiply the remainder by the length of the pipes in feet, and again by the constant number or coefficient* 1·68; *then divide the product by the diameter of the pipe in inches drawn into the velocity of the steam in feet per second, and the quotient will express the diminution of temperature in degrees of Fahrenheit's thermometer.*

Example. Let the length of the steam pipe be 16 feet and its diameter 5 inches, and suppose the velocity of the steam to be about 95 feet per second, what will be the diminution of temperature, on the supposition that the steam is at 250° and the external air at 60° of Fahrenheit?

Here, by the note to the above rule, the temperature of the surface of the steam pipe is $250 - 250 \times 0{\cdot}05 = 237{\cdot}5$; hence we get $t'' = \frac{1{\cdot}68 \times 16(237{\cdot}5-60)}{5 \times 95} = 10{\cdot}044$ degrees.

If we examine the manner of the composition of the above equation, it will be perceived that, since the diameter of the pipe and the velocity of motion enter as divisors, the loss of heat will be less as these factors are greater; but, on the other hand, the loss of heat will be greater in proportion to the length of pipe and the temperature of the steam. Since the steam is reduced from a higher to a lower temperature during its passage through the steam pipes, it must be attended with a corresponding diminution in the elastic force; it therefore becomes necessary to ascertain to what extent the force is reduced, in consequence of the loss of heat that takes place in passing along the pipes. This is an inquiry of some importance to the manufacturers of steam engines, as it serves to guard them against a very common mistake into which they are liable to fall, especially in reference to steam boat engines, where it is usual to cause the pipe to pass round the cylinder, instead of carrying it in the shortest direction from the boiler, in order to decrease the quantity of surface exposed to the cooling effect of the atmosphere.

Let f = the elastic force of steam in the boiler, corresponding to the given temperature; and
f' = the force to which it is reduced in passing along the pipes, in consequence of the reduction of temperature.

Then, by subtraction, we have $f-f'$ for the quantity of reduction by cooling; but, during the process of reduction, a part of the steam is converted into water; hence we get $f : 1 :: f-f' : \frac{f-f'}{f}$ = the quantity reduced to water; consequently, if this be multiplied by 1000°, which is the heat of conversion into steam according to Dr. Ure's experiments, the product must be equal to the quantity of heat the whole has lost by cooling in passing through the pipes; therefore, by comparison, we get

$$\frac{1{\cdot}68l\,(t-t')}{dv} = \frac{1000\,(f-f')}{f};$$

and, by reducing this expression in reference to f', it is

$$f' = f\left\{1 - \frac{0{\cdot}00168l\,(t-t')}{dv}\right\} \qquad (c).$$

---

* From the result of numerous experiments that have been performed for the purpose of ascertaining this datum, it may on an average be taken at one twentieth less than the temperature of the steam $t = \text{T}\,(1-\frac{1}{20})$, where T is the temperature of the steam in the boiler.

This equation gives the elastic force of the steam as reduced by cooling in flowing along the steam pipes; it is sufficiently simple for every practical purpose, and the method of reducing it is as follows.

RULE. *From the temperature of the surface of the steam pipe subtract the temperature of the external air; multiply the remainder by the length of the pipe in feet, and again by the constant fractional coefficient* 0·00168; *divide the product by the diameter of the pipe in inches drawn into the velocity of steam in feet per second, and subtract the quotient from unity; then multiply the difference thus obtained by the elastic force corresponding to the temperature of steam in the boiler, and the product will be the elastic force of the steam as reduced by cooling in passing through the pipes.*

Example. Let the dimensions of the pipe, the temperature of the steam, and its velocity through the passages, be the same as in the preceding example, what will be the quantity of reduction in the elastic force occasioned by the effect of cooling in traversing the steam pipe?

Since the elastic force of the steam in the boiler enters the equation from which the above rule is deduced, it becomes necessary in the first place to calculate its value; and this is to be done by the second clause of the rule on the first column of page 41., which answers to the case in which the temperature is greater than 212°; thus we have

$$
\begin{array}{rll}
250 \times 1{\cdot}69856 = 424{\cdot}640 & & \\
\text{Constant number} = \underline{205{\cdot}526} \text{ add} & & \\
\text{Sum} = 630{\cdot}166 & - & \log.\ 2{\cdot}79945 \\
\text{Constant divisor} = 333 \quad - & - & \log.\ \underline{2{\cdot}522444} \text{ subtract} \\
& & 0{\cdot}277011 \times 6{\cdot}42 = 1{\cdot}778410,
\end{array}
$$

which is the logarithm of 60·036 inches of mercury.

Again, we have $250 - 0{\cdot}05 \times 250 = 237{\cdot}5$; consequently, by multiplying as directed in the rule, we get $237{\cdot}5 \times 0{\cdot}00168 \times 16 = 6{\cdot}384$, which being divided by $95 \times 5 = 475$, gives 0·01344; and by taking this from unity and multiplying the remainder by the elastic force as calculated above, the value of the reduced elastic force becomes

$$f' = 60{\cdot}036\ (1 - 0{\cdot}01344) = 59{\cdot}229 \text{ inches of mercury.}$$

The loss of force is therefore $60{\cdot}036 - 59{\cdot}229 = 0{\cdot}807$ inches of mercury, which amounts to the $\frac{1}{75}$th part of the entire elastic force of the steam in the boiler as generated under the given temperature, being a quantity of sufficient importance to claim the attention of our engineers.

FEED WATER.

The quantity of water required to supply the waste occasioned by evaporation from a boiler, or, as it is technically termed, the "feed water" required by a boiler working with any given pressure, is easily determinable. For since the relative volumes of water and steam at any given pressure are known, it becomes necessary merely to restore the quantity of water by the feed pump equivalent to that abstracted in the form of steam, which the known relation of the density to the pressure of the steam renders of easy accomplishment. In practice, however, it is necessary that the feed pump should be able to supply a much larger quantity of water than what theory prescribes, as a great waste of water sometimes occurs from leakage or priming, and it is necessary to provide against such contingencies. The feed pump is usually made of such dimensions as to be capable of supplying 3½ times the water that the boiler will evaporate, and in low pressure engines, where the cylinder is double acting and the feed pump single acting, this proportion will be maintained by making the pump a 240th of the capacity of the cylinder. In low pressure engines the pressure in the boiler may be taken at 5 lbs. above the pressure of the atmosphere, or 20 lbs. in all; and as high pressure steam is merely low pressure steam compressed into a smaller compass, the size of the feed pump relatively to the size of the cylinder must obviously vary in the direct proportion of the pressure. If, then, the feed pump be 1-240th of the capacity of the cylinder when the total pressure of the steam is 20 lbs., it must be 1-120th of the capacity of the cylinder when the total pressure of the steam is 40 lbs., or 25 lbs. above the atmosphere. This law of variation is expressed by the following rule, which gives the capacity of feed pump proper for all pressures:—Multiply the capacity of the cylinder in cubic inches by the *total* pressure of the steam in lbs. per square inch, or the pressure in lbs. per square inch on the safety valve, plus 15, and divide the product by 4800; the quotient is the capacity of the feed pump in cubic inches, when the feed pump is single acting and the engine double acting. If the feed pump be double acting, or the engine single acting, the capacity of the pump must be just one half what is given by this rule.

CONDENSING WATER.

Mr. Watt found that the most beneficial temperature of the hot well of his engines was 100 degrees. If, therefore, the temperature of the steam be 212°, and the latent heat 1000°, then 1212° may be taken to represent the heat contained in the steam, or 1112° if we deduct the temperature of the hot well. If the temperature of the injection water be 50°, then 50 degrees of cold are available for the abstraction of heat, and as the total quantity of heat to be abstracted, is that requisite to raise the quantity of water in the steam 1112 degrees, or 1112 times that quantity, one degree, it would raise one-fiftieth of this, or 22·24 times the quantity of water in the steam, 50 degrees. A cubic inch of water therefore raised into steam will require 22·24 cubic inches of water at 50 degrees for its condensation, and will form therewith 23·24 cubic inches of hot water at 100 degrees. Mr. Watt's practice was, to allow about a wine pint (28·9 cubic inches) of injection water for every cubic inch of water evaporated from the boiler. The usual capacity for the cold water pump is $\frac{1}{24}$th of the capacity of the cylinder, which allows some water to run to waste. As a maximum effect is obtained when the temperature of the hot well is about 100°, it will not be advisable to reduce it below that temperature in practice. With the superior vacuum due to a temperature of 70° or 80° the admission of so much cold water into the condenser becomes necessary,—and which has afterwards to be pumped out in opposition to the pressure of the atmosphere,—that the gain in the vacuum does not equal the loss of power occasioned by the additional load upon the pump, and there is therefore a clear loss by the reduction of the temperature below 100°, if such reduction be caused by the admission of an additional quantity of water. If the reduction of temperature, however, be caused by the use of colder water, there is a gain produced by it, though the gain will within certain limits be greater, if advantage be taken of the lowness of the temperature to diminish the quantity of injection.

SAFETY VALVES.

It is not difficult to ascertain the dimensions of an orifice in a boiler of given evaporative power, which shall permit such an escape of steam as will prevent the pressure from exceeding any assigned amount.

For this purpose,

Let t = the maximum temperature to which it is wished the steam should rise.

f = corresponding elastic force measured in inches of mercury.

Let N = number of cubic feet of water that can be converted into steam in one hour.

Therefore from formula (V) (page 42.) the number of cubic feet of steam having temperature t and corresponding force f, that can be produced in one hour, is equal to

$$\frac{75{\cdot}67 \times (459 + t) \times \mathrm{N}}{f}$$

Let x = Area in square inches of the orifice of the safety valve.

V = Velocity in feet per second of the escape into air of steam at temperature t and force f.

Then there escapes per second $\frac{x\,\mathrm{V}}{144}$ cubic feet of steam, and per hour $25\,x\,\mathrm{V}$. Now the orifice of the valve ought to be so regulated as to allow the steam to escape as fast as it can be formed in the boiler; therefore

$$25\,x\,\mathrm{V} = \frac{75{\cdot}67 \times (459 + t) \times \mathrm{N}}{f}$$

therefore,

$$x = \frac{3{\cdot}0268 \times (459 + t) \times \mathrm{N}}{f\mathrm{V}}$$

But since steam at a temperature of 212° balances the atmosphere, we may conclude that the steam will escape at the same rate into the air as it would into steam at a temperature of 212°. Hence we may apply the principle mentioned in page 43:—

Let h = height of a column capable of producing a pressure f.

h' = height of a column capable of producing the pressure of the atmosphere.

Then from formula 11 (page 43.) we obtain $\mathrm{V} = 5\sqrt{h - h'}$. But if v denote relative volume of steam at temperature t, then $h = 1{\cdot}1341\,f\,v$, and $h' = 1{\cdot}1341\,f'\,v$; where f' denotes the pressure of the atmosphere in inches of mercury,

$$\therefore \mathrm{V} = 5\sqrt{1{\cdot}1341\ v\,(f - f')} = 5{\cdot}322\sqrt{v\,(f - f')}$$

Substituting the value of v from formula U (page 42.), and denoting $\frac{f - f_1}{f}$ by n, we obtain

$$
\begin{aligned}
\mathrm{V} &= 5{\cdot}322\sqrt{75{\cdot}67 \times n \times (459 + t)} \\
&= 46{\cdot}32\sqrt{n \times (459 + t)}
\end{aligned}
$$

Substituting this Value of V, we obtain

$$
\begin{aligned}
x &= \frac{3{\cdot}0268 \times (459 + t) \times \mathrm{N}}{46{\cdot}32 \times f\ \sqrt{n \times (459 + t)}} \\
&= {\cdot}0653\ \frac{\sqrt{459 + t}}{f\sqrt{n}}\,\mathrm{N} \\
&= {\cdot}0653 \times \mathrm{N}\sqrt{\frac{459 + t}{f(f - f_1)}}
\end{aligned}
$$

From this formula we derive the following rule:—

RULE.—*Add* 459 *to the temperature of the steam in degrees of* Fahrenheit; *divide the sum by the product of the elastic force of the steam in inches of mercury, into its excess above the weight of the atmosphere in inches of mercury; multiply the square root of the quotient by* ·0653; *multiply this product* *by the number of cubic feet per hour of water evaporated, and this last product is the theoretical area of the orifice of the safety-valve in square inches.*

To apply this to an example — which, however, it must be remembered, will give a result much too small for practice.

Required the least area of a safety valve of a boiler suited for a 250 horse power engine, working with steam 6 lbs. more than the atmosphere on the square inch.

In this case the total pressure is equal to 21 lbs. per square inch; and as in round numbers one pound of pressure is equal to about two inches of mercury, it follows that $f=42$ inches of mercury.

It will be necessary to calculate t from formula (S) page 41. The operation is as follows: —

$$\begin{array}{rr} \text{log. } 42 \div 6{\cdot}42 = 1{\cdot}623249 \div 6{\cdot}42 = & 0{\cdot}252842 \\ \text{constant coefficient} = 196 \qquad & 2{\cdot}292363 \\ \hline & 2{\cdot}545205 \end{array}$$

$$\begin{array}{r} \text{natural number} = 350{\cdot}92 \\ \text{constant temperature} = 121 \\ \hline t = 229{\cdot}92 \end{array}$$

$$\text{therefore } \sqrt{\frac{459+t}{f(f-30)}} = \sqrt{\frac{459+229{\cdot}92}{42 \times 12}}$$

$$= \sqrt{\frac{688{\cdot}92}{50{\cdot}4}} = \sqrt{1{\cdot}3669} = 1{\cdot}168$$

$$\text{therefore } x = {\cdot}0653 \times 1{\cdot}168 \times N = {\cdot}0757 \ N.$$

We have stated in a former part of this work that a cubic foot of water evaporated per hour is equivalent to one horse power; therefore in this case $N=250$ and $x=18{\cdot}925$ sq. in.

As another example. Required the proper area of the safety-valve of a boiler suited to an engine of 500 horse power, when it is wished that the steam should never acquire an elastic force greater than 60 lbs. on the square inch above the atmosphere.

In this case the whole elastic force of the steam is 75 lbs.; and as 1 lb. corresponds in round numbers to 2 inches of mercury, it follows that $f=150$. It will be necessary to calculate the temperature corresponding to this force. The operation, as performed by formula S, page 41., is as follows: —

$$\begin{array}{rll} \text{Log. } 150 \div 6{\cdot}42 = 2{\cdot}176091 \div 6{\cdot}42 = & & {\cdot}338955 \\ \text{constant coefficient} = & 196 & \text{log. } 2{\cdot}292363 \text{ add} \\ \text{natural number} = & 427{\cdot}876 & \overline{2{\cdot}631318} \\ \text{constant temperature} = & 121 & \\ \text{required temperature} & 306{\cdot}876 & \text{degrees of Fahrenheit's scale} \end{array}$$

$$\text{therefore } \frac{459+t}{f(f-30)} = \frac{459+306{\cdot}876}{150\,(150-30)} = \frac{765{\cdot}876}{150 \times 120} = \frac{765{\cdot}896}{18000}$$

$$= {\cdot}043549; \text{ therefore } \sqrt{\frac{459+t}{f(f-30)}} = \sqrt{{\cdot}042549} = {\cdot}20628$$

Hence the required area $= {\cdot}0653 \times {\cdot}20628 \times 500 = {\cdot}01347 \times 500 = 6{\cdot}735$ square inches.

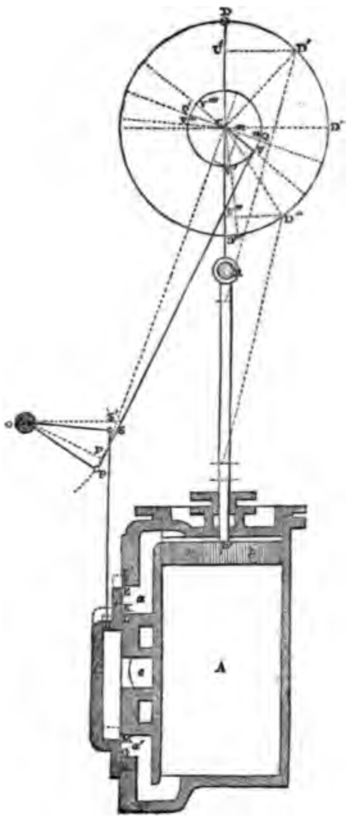
If the area of the safety-valve of a boiler suited for an engine of 500 horse power be required, when it is wished the steam should never acquire a greater temperature than 300°, it will be necessary to calculate the elastic force corresponding to this temperature; and by formula Q, page 40., the required area $= {\cdot}0653 \times {\cdot}231 \times 500 = {\cdot}0151 \times 500 = 7{\cdot}55$ square inches. It will be perceived from these examples that the greater the elasticity and the higher the corresponding temperature the less is the area of the safety-valve. This is just as might have been expected, for then the steam can escape with increased velocity. We may repeat that the results we have arrived at are much less than those used in practice. For the sake of safety the orifices of the safety-valve are intentionally made much larger than what theory requires; usually $\frac{1}{10}$ of a square inch per horse power is the ordinary proportion allowed in the case of low pressure engines.

SLIDE VALVE.

We shall first find a formula which — the dimensions of the valve eccentric, &c., being given — will enable us to find the exact position of the valve, corresponding to any given part of the stroke of the piston; and then a formula to give conversely the position of the piston corresponding to any given position of the valve. We shall then find another formula to determine the cover and length of stroke of the valve that are requisite to cut the steam off at any given part of the stroke. These formulas we shall illustrate by examples, and subjoin a digest of the whole in three practical rules, with examples for the use of those who are not familiar with algebraic notation.

We shall suppose *fig.* 2. plate 4. to represent a steam engine cylinder, crank, and short slide-valve. A A is the cylinder, $v\,v$ the valve, $a\ a'$ the steam ports, e the exhausting port. H S is the valve rod connected with the lever O S, which works on a shaft whose centre is at O. On the same shaft is another lever, O P, to which the eccentric connecting-rod is attached by a pin at P. C is the centre of the fly-wheel shaft, C D the length of the crank, and C V the radius * of the eccentric. R D represents the connecting-rod when the piston is at the top of the stroke. $p\,p$ is the piston, and R p' is the piston-rod. The valve, as shown in dotted lines, is at its middle position, or half stroke. When the piston is at the top of its stroke, however, the valve must be in the position shown by the sectional lines.

Fig. 161.



The space F E′ which the valve overlaps the steam port, we call the cover on the steam side. J K, the overlap on the other side of the port, we call the cover on the exhausting side. It is usual to have the valve so adjusted that the steam port may be slightly open when the piston is at the top or bottom of its stroke. The space thus open, F E, we call the lead. In adjusting the length of the valve-rod P V, care must be taken that the length is such that when the eccentric is in the position C Q, at right angles to C P, the valve may be exactly in its middle position; that is, that the overlap F E′ may be the same as the overlap G H at the other side. When the length of the valve-rod is thus determined, the proper position of the eccentric on the shaft may then be ascertained by placing the crank in the perpendicular position, as shown in the figures, and turning the eccentric round into a position C V, such that the valve will be pushed downwards so far as to cause the port a just to begin to be opened at F E. The eccentric may then be fixed firm to the shaft.

To facilitate the following investigations, we shall denote the various parts by different letters thus: —

r = radius of the crank.
† r' = radius of eccentric, or half the stroke of the valve.
s = distance of the piston at any moment from the top of its stroke.
s' = distance of the valve at the corresponding time from top of *its* stroke.
x = arc travelled over by the crank (measuring from the perpendicular position C D) while the piston has moved over a space $= s$.
c = cover of the valve on the steam side.
c' = cover of the valve on the exhausting side.
l = lead of the valve.

We are now prepared to investigate a formula to give the value of s' a any part of the stroke.

We shall, in what follows, suppose the valve-rod P V, and the connecting-rod, to be both indefinitely long, in comparison with the length of their respective cranks C V and C D; or, in other words, we shall consider these rods to be always parallel to the lines C P and C p'. This, of course, can never be exactly true; but in almost every case the error thus introduced is small in amount, or at least of such a kind as to produce no error in the results* of any practical importance.

---

* "Radius of the eccentric." Every one who has given the least degree of consideration to the working of the eccentric, knows that it produces exactly the same motion as a small crank whose radius is equal to the distance between the centre of the eccentric ring and the centre of the shaft. In this paper, therefore, we shall speak of the eccentric as if it were in reality such a small crank.

† It may be as well to observe that the levers that work the valve are, in the figure, supposed to be equal, and of course the stroke of the valve is just double the radius of the eccentric. When the levers are unequal, this will no longer be the case; but in using the formulas that follow, r' must be taken as half the stroke of the valve, no matter what the radius of the eccentric may be.
]

When the crank is in any position C D′, the distance s will evidently be equal to D U; that is, to $r-r\cos x$, and this will be the value of s in any part of the revolution; for, after the crank passes the horizontal line C D″, the cosines of s become negative. Thus, when the crank is in the position C D‴, s will be equal to D U‴, or to $r-r$ cos. x, the same as before. We have, therefore,

$$\left.\begin{array}{r} s=r-r\cos. x \\ \text{or } s=r(1-\cos. x) \end{array}\right\} (a)$$

Again, when the crank is in any position C D′, the eccentric will also have moved over an arc V V′, equal D D′ or to x. So that the distance s' will be equal to kf, or to $r'+\mathrm{V}'m$.

That is, $s'=kf$

But $kf=r-r$ cos. arc V V′ k.

Now the arc V′ V k may be considered as made up of three parts, viz. k V or 90°, V V′ or x, and lastly, Q V, the length of which is determined by the quantity of cover (c) and the lead (l); the arc V Q being always such that its sine multiplied by r' may be equal to $c+l$. We shall therefore have,

$$\text{arc } k\,\mathrm{V}\,\mathrm{V}'=90^\circ+\sin.^{-1}\frac{c+l}{r'}+x\dagger$$

For simplicity in the notation let us put

$$90^\circ+\sin.^{-1}\frac{c+l}{r'}=d$$

$$\text{Then, arc } k\,\mathrm{V}\,\mathrm{V}'=d+x$$

$$\text{And } kf=r'-r'\cos.(d+x)$$

$$\text{But } kf=s'$$

$$\therefore s'=r'-r'\cos.(d+x)$$

$$\left.\begin{array}{r} \text{Or } s'=r'\left\{1-\cos.(d+x)\right\} \\ \text{Or } s'=r'\text{ vers.}(d+x) \end{array}\right\} (b).$$

Now the arc x is evidently equal to the arc whose versed sine to the radius r is equal to s, that is,

$$x=\text{vers.}^{-1}\frac{s}{r}$$

$$\text{Or } x=\cos.^{-1}\left(\frac{r-s}{r}\right)$$

Substituting, therefore, in the last two equations, the values of x and d, we shall have

$$\left.\begin{array}{r} s'=r'\left\{1-\cos.\left(90^\circ+\sin.^{-1}\frac{c+l}{r}+\cos.^{-1}\frac{r-s}{r}\right)\right\} \\ \text{Or } s'=r'\text{ vers.}\left(90^\circ+\sin.^{-1}\frac{c+l}{r}+\text{vers.}^{-1}\frac{s'}{r}\right) \end{array}\right\} \;.\;.\;(\mathrm{A})$$

Again, from formula (b) we have

$$r'-s'=r'\cos.(d+x)$$

$$\therefore \frac{r'-s'}{r'}=\cos.(d+x)$$

$$\text{Hence, } d+x=\cos.^{-1}\frac{r'-s'}{r'}$$

$$\therefore x=\cos.^{-1}\frac{r'-s'}{r'}-d$$

Substituting this value of x in formula (a) we have,

$$s=r\left\{1-\cos.\left(\cos.^{-1}\frac{r'-s'}{r'}-d\right)\right\}$$

$$\text{Or } s=r\text{ vers.}\left(\cos.^{-1}\frac{r'-s'}{r'}-d\right)\Bigg\}$$

Substituting for d its value, we get,

$$\left.\begin{array}{r} s=r\left\{1-\cos.\left(\cos.^{-1}\frac{r'-s'}{r'}-90^\circ-\sin.^{-1}\frac{c+l}{r'}\right)\right\} \\ \text{Or } s=r\text{ vers.}\left(\text{vers.}^{-1}\frac{s'}{r'}-90^\circ-\sin.^{-1}\frac{c+l}{r'}\right) \end{array}\right\} (\mathrm{B})$$

Either of the formulas (A) will readily enable us to find, by the aid of a table of natural sines, the value of s', or the position of the valve for any value of s, and conversely either of the formulas (B) will give us the value of s, corresponding to any value of s'.

We may now proceed to investigate a formula that will give the amount of the cover on the steam side that is requisite to cause the steam to be cut off at any required part of the stroke.

The steam, when the piston is going down, will be cut off when the edge of the valve E comes to the edge of the port F during the upward motion of the valve. Now this will happen when the eccentric is in some position C V‴, such that the sine of the arc V‴ Q′ is equal to the cover on the steam side. But when the crank has made half a revolution, or reached its lowest position, the eccentric will also have made half a revolution, and will be in the position C V⁗. It thus appears that, when the steam is cut off, the crank has described an arc of 180 degrees, minus the arc V‴ V⁗. Supposing, therefore, that C D‴ represents the position of the crank when the steam is cut off, we will have the arc D D″ D‴ = arc V V′ V″. But the distance of the piston from the top of the cylinder, when the steam is cut off (call this distance s'') is equal to the radius of the crank (r), plus the cosine C U‴ of the arc D‴ D⁗. We have, therefore,

$$s''=r+r\cos.\,\mathrm{D}'''\,\mathrm{D}''''=r+r\cos.\,\mathrm{V}'''\,\mathrm{V}^4$$

$$\therefore \cos.\,\mathrm{V}'''\,\mathrm{V}^4=\frac{s''-r}{r}\qquad(f)$$

Again, this arc V‴ V^4 is composed of two arcs Q′ V‴ and Q′ V^4.

Sine Q′ V‴ to radius r' we have already seen is equal to the required cover on the steam side, that is, sin. Q′ V‴ $=\frac{c}{r'}$, and since Q′ V^4 = Q V, we have

$$\sin.\,\mathrm{Q}'\,\mathrm{V}^4=\frac{c+l}{r'}$$

The lead is generally very small, and therefore these two arcs, Q′ V^4 and Q′ V‴, are very nearly equal: so that it will be sufficiently accurate for practical purposes if we make c, the required cover on the steam side, equal to

$$r'\sin.\tfrac{1}{2}\text{ arc }\mathrm{V}'''\,\mathrm{V}^4-\tfrac{1}{2}l,\ \text{That is, } c=\sin.\tfrac{1}{2}\text{ arc }\mathrm{V}'''\,\mathrm{V}^4-\tfrac{1}{2}l\qquad(g)$$

By a well-known trigonometrical formula,

$$\sin.\tfrac{1}{2}\,\mathrm{V}'''\,\mathrm{V}^4=\sqrt{\left(\frac{1-\cos.\,\mathrm{V}'''\,\mathrm{V}^4}{2}\right)}$$

Substituting in this the value of V‴ V^4, from formula (f), we get

$$\sin.\tfrac{1}{2}\,\mathrm{V}'''\,\mathrm{V}^4=\sqrt{\left\{\frac{1-\frac{s''-r}{r}}{2}\right\}}$$

$$\therefore \sin.\tfrac{1}{2}\,\mathrm{V}'''\,\mathrm{V}^4=\sqrt{\left(\frac{2r-s''}{2r}\right)}$$

$$\text{Hence }(g),\ c=r'\sqrt{\left(\frac{2r-s''}{2r}\right)}-\tfrac{1}{2}l\quad(\mathrm{C})$$

The cover that is necessary on the steam side to cause the steam to be cut off at any proposed part of the stroke, may be ascertained from this formula, by substituting for s'', in the second member, the proposed length of stroke to be made before the steam is cut off.

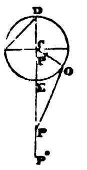
The three formulas A, B, and C, which we have now investigated, will enable the engineer to solve any questions that are likely to arise respecting the working of the slide-valve, and will frequently obviate the necessity of the very common practice of making wooden models of the valve to see how it will work, or how much cover it ought to have. The formulas are easily worked, and require in general but little calculation. The only auxiliary required is a table of natural sines, which is to be found in almost every collection of trigonometrical tables.

As an example of the application of formula (C)

			inches.
Let the stroke of the engine . .		=	60
Or	r	=	30
The stroke of the valve . . .		=	10
Or	r'	=	5
Lead		=	¼
s''		=	45

It is required to find how much cover the valve should have on the steam side to make the steam be cut off, when the piston is 45 inches from the beginning of the stroke. We have (C)

$$c=5\sqrt{\left(\frac{60-45}{120}\right)}-\tfrac{1}{8}=2\tfrac{3}{8}$$ inches, the amount of cover required to produce the given amount of expansion.



* It may be satisfactory to the reader that we should make a few remarks, to show how it is that the errors thus introduced into our investigations are of no practical importance. First, with regard to the shortness of the connecting-rod, the error introduced by it arises from the circumstance that the crank is not horizontal at half stroke of the piston. Thus suppose C O in the figure to be the crank, and O P the connecting-rod. Suppose P′ and P″ to be the extremities of the stroke of the point P. P′ D and P″ E will both be equal to P O, and therefore, if P is the position of the cross-head at half stroke, P C will also be equal to P O. Hence it is that the crank must always be below the horizontal line at half stroke, and the shorter the connecting-rod is in proportion to the crank, the more will the crank at half stroke deviate from the horizontal position.

The motion of the valve, however, not being affected by the shortness of the connecting-rod, will, so far as *it* is concerned, work, in relation to the crank, exactly as if the connecting-rod were infinitely long. That is, when the crank is horizontal, the valve will be in the position properly corresponding to half-stroke.

This, it will be readily perceived, is of no consequence to the working of the engine. The grand point is to get the valve to work correctly at the critical moment when the piston approaches either end of its stroke, and is changing the direction of its motion.

The derangement produced by a short eccentric-rod is of little practical importance from the same cause.

The valve being placed correctly when the piston is at the end of the stroke, the only effect of the short valve connecting-rod, will be to make the valve travel a little farther one way than it does the other, or, what is the same thing, the valve will be a little more open at half stroke, when the piston is going one way, than when it is going the other.

† Sin -1 A, means the arc whose sine is equal to A. Cos.-1 A means the arc whose cosine is equal to A, and so on.

As an example of the application of formula (C), we may apply it to the same case.

We have found that the cover should be 2⅜ inches to make the steam be cut off at three-quarters of the stroke. By formula (C) we may now verify our calculation, and—supposing the valve to be made with a cover of 2⅜ inches—we can see whether or not it will cut the steam off at the proper part of the stroke.

Supposing the piston to be moving downwards, when the steam is cut off, the valve is below its middle position by the length of the cover 2⅜ inches, and when at its middle position, it is half the length of its stroke (5 inches) below its highest position; hence $s' = 7\frac{3}{8}$, or $s' = 7{\cdot}375$. The values of the other letters will be the same as before. We will have, therefore,

$$\cos.^{-1} \frac{r' - s'}{r'} = \cos.^{-1} - {\cdot}475 = 118\tfrac{1}{2}^\circ \text{ or } 241\tfrac{1}{2}^\circ$$

Both these arcs have their cosines equal to $-{\cdot}475$; so that we may take either of them.

$$\text{Also, } \sin.^{-1} \frac{c + l}{r'} = \sin.^{-1} {\cdot}525 = 23^\circ$$

and we have (C)

$$s = r \left\{ 1 - \cos. (118\tfrac{1}{2}^\circ - 90^\circ - 32^\circ) \right\} = r \left\{ 1 - \cos. 3\tfrac{1}{2}^\circ \right\}$$

$$\text{Or, } s = r \left\{ 1 - \cos. (241\tfrac{1}{2}^\circ - 90^\circ - 32^\circ) \right\} \quad r \left\{ 1 - \cos. 119\tfrac{1}{2}^\circ \right\}$$

according as we take the first or second value of $\cos.^{-1} \frac{r' - s'}{r'}$

$$\begin{gathered} \text{Now, } \cos. 3\tfrac{1}{2}^\circ = 0{\cdot}9981 \\ \text{And, } \cos. 119\tfrac{1}{2}^\circ = -0{\cdot}4924 \\ \text{Hence, } s = 30\,(1 - {\cdot}9981) \\ \text{Or, } s = 30\,(1 + {\cdot}4924) \\ \therefore s = {\cdot}057, \text{ or } 44{\cdot}76. \end{gathered}$$

The second value of s is evidently the one required for our present purpose, and shows that the steam will be cut off at 44·76 inches from the beginning of the stroke, which agrees very nearly with our former calculation, which made a cover of 2⅜ inches cut the steam off at 45 inches from the beginning of the stroke.

With regard to the above calculation it may be remarked, that there are an infinite number of arcs which have their cosines equal to —·475; but if we were to take more of these arcs it would be found, that they would ultimately all give one or other of the results we have already obtained, so that it is unnecessary to take more than the first two of them.

The reason that we get two values for s, is this. For each position of the valve there are two corresponding positions of the piston; the one being its corresponding position when going downwards, and the other when going upwards. The second value we got for s, therefore, shows us that when the piston is moving upwards, the valve will begin to open the port, a, when the piston is ·057 inch from the top of its stroke. By increasing the cover on the steam side of the valve, any amount of expansion may be obtained, and we might thus obviate the necessity of using expansion-valves, were it not that increasing the cover on the steam side beyond moderate limits deranges the working of the exhausting ports. A valve with much cover on the steam side must always shut the exhausting port considerably before the piston has reached the end of the stroke, while it at the same time opens a passage to the condenser for the steam that is acting expansively, and thereby entirely removes the propelling power before the piston has completed its stroke. In the valve we have taken as an example, the operation of this kind of valve in producing expansion is carried too far, or at least to the utmost allowable limits. As another example of the use of formula (C) we shall apply it to the same valve to ascertain to what extent the objections we have just described apply in this instance. Let us suppose that the cover on the exhausting side (c') is ½ inch, we would then have the exhaustion below the piston cut off when the valve is 5½ inches below its highest position.

In other words we will have $s' = 5\frac{1}{2}$.

$$\text{Then, } \cos.^{-1} \frac{r' - s'}{r'} = \cos.^{-1} - {\cdot}1. = 96^\circ \text{ or} = 264^\circ$$

$$\text{And as before, } \sin^{-1} \frac{c + l}{r'} = 32^\circ$$

$$\begin{gathered} \text{Hence } s = 30\,(1 - \cos. 26^\circ) \text{ or } 30\,(1 - \cos. 142^\circ) \\ \therefore s = 3{\cdot}03 \text{ or } s = 53{\cdot}64 \end{gathered}$$

We thus see that the exhaustion below the piston would be cut off when the piston is still about 6½ inches from the bottom of its stroke. The other value of s shows that, when the piston is going upwards, the exhausting passage for the steam below it would be opened when the piston was still 3·03 inches from the top of the stroke.

In what precedes we have spoken exclusively of the common short slide-valve, such as is represented in the figure; but the long D valve works on exactly the same principle; only in it the exhausting sides of the ports are usually reversed. The steam generally enters the cylinder from the insides of the ports, that is, from K and M, and exhausts at F and G.

The formula (C) however will apply to the long slide without alteration, and the other two formulas (A and B) require only one sign to be changed. For the long D valve these two formulas will stand thus:—

$$\left.\begin{aligned} s' &= r \left\{ 1 - \cos. \left(90^\circ - \sin.^{-1} \frac{c + l}{r'} + \cos.^{-1} \frac{r - s}{r} \right) \right\} \\ \text{or } s' &= r. \text{ vers. } \left(90^\circ - \sin.^{-1} \frac{c + l}{r'} + \text{vers. } \frac{s}{r} \right) \end{aligned}\right\} \quad \text{(A)}$$

$$\left.\begin{aligned} s &= r \left\{ 1 - \cos. \left(\cos.^{-1} \frac{r' - s'}{r'} - 90^\circ + \sin.^{-1} \frac{c + l}{r} \right) \right\} \\ \text{or } s &= r. \text{ vers. } \left(\text{vers.}^{-1} \frac{s'}{r'} - 90^\circ + \sin.^{-1} \frac{c + l}{r} \right) \end{aligned}\right\} \quad \text{(B)}$$

The principal results of the foregoing observations may be expressed in the four following practical rules, applicable alike to short slide and long D valves.

Rule I.—*To find how much cover must be given on the steam side in order to cut the steam off at any given part of the stroke.*

From the length of the stroke of the piston, subtract the length of that part of the stroke that is to be made before the steam is cut off. Divide the remainder by the length of the stroke of the piston, and extract the square root of the quotient. Multiply the square root thus found by half the length of the stroke of the valve, and from the product take half the lead, and the remainder will be the cover required.

Rule II.—*To find at what part of the stroke any given amount of cover on the steam side will cut off the steam.*

Add the cover on the steam side to the lead; divide the sum by half the length of stroke of the valve. In a table of natural sines find the arc whose sine is equal to the quotient thus obtained. To this arc add 90°, and from the sum of these two arcs subtract the arc whose cosine is equal to the cover on the steam side divided by half the stroke of the valve. Find the cosine of the remaining arc, add 1 to it, and multiply the sum by half the stroke of the piston, and the product is the length of that part of the stroke that will be made by the piston before the steam is cut off.

Rule III.—*To find how much before the end of the stroke, the exhaustion of the steam in front of the piston will be cut off.*

To the cover on the steam side add the lead, and divide the sum by half the length of the stroke of the valve. Find the arc whose sine is equal to the quotient, and add 90° to it. Divide the cover on the exhausting side by half the stroke of the valve, and find the arc whose cosine is equal to the quotient. Subtract this arc from the one last obtained, and find the cosine of the remainder. Subtract this cosine from 2, and multiply the remainder by half the stroke of the piston. The product is the distance of the piston from the end of its stroke when the exhaustion is cut off.

Rule IV.—*To find how far the piston is from the end of its stroke, when the steam that is propelling it by expansion is allowed to escape to the condenser.*

To the cover on the steam side add the lead, divide the sum by half the stroke of the valve, and find the arc whose sine is equal to the quotient. Find the arc whose cosine is equal to the cover on the exhausting side, divided by half the stroke of the valve. Add these two arcs together, and subtract 90°. Find the cosine of the residue, subtract it from 1, and multiply the remainder by half the stroke of the piston. The product is the distance of the piston from the end of its stroke, when the steam that is propelling it is allowed to escape to the condenser. In using these rules all the dimensions are to be taken in inches, and the answers will be found in inches also.

From an examination of the formulas we have given on this subject, it will be perceived (supposing that there is no lead) that the part of the stroke where the steam is cut off, is determined by the proportion which the cover on the steam side bears to the length of the stroke of the valve: so that in all cases where the cover bears the same proportion to the length of the stroke of the valve, the steam will be cut off at the same part of the stroke of the piston.

In the first line, accordingly, of Table I., will be found eight different parts of the stroke of the piston designated; and directly below each, in the second line, is given the quantity of cover requisite to cause the steam to be cut off at that particular part of the stroke. The different sizes of the cover are given in the second line, in decimal parts of the length of the stroke of the valve; so that, to get the quantity of cover corresponding to any of the given degrees of expansion, it is only necessary to take the decimal in the second line, which stands under the fraction in the first, that marks that degree of expansion, and multiply that decimal by the length you intend to make the stroke of the valve. Thus suppose you have an engine in which you wish to have the steam cut off when the piston is a quarter of the length of its stroke from the end of it, look in the first line of the table, and you will find in the third column from the left, ¼. Directly under that, in the second line, you have the decimal, ·250. Suppose that you think 18 inches will be a convenient length for the stroke of the valve, multiply the decimal ·250 by 18, which gives 4½. Hence we learn, that with an 18-inch stroke for the valve $4\frac{1}{2}$ inches of cover on the steam side will cause the steam to be cut off when the piston has still a quarter of its stroke to perform.

Half the stroke of the valve must always be *at least* equal to the cover on the steam side added to the breadth * of the port; consequently, as the cover, in this case, must be $4\frac{1}{2}$ inches, and as half the stroke of the valve is 9 inches, the breadth of the port cannot be more than $(9-4\frac{1}{2}=4\frac{1}{2})$ $4\frac{1}{2}$ inches. If this breadth of port is not enough, we must increase the stroke of the valve; by which means we shall get both the cover and the breadth of the port proportionally increased. Thus, if we make the length of valve-stroke 20 inches, we shall have for the cover ·250 × 20 = 5 inches, and for the breadth of the port 10 — 5 = 5 inches.

TABLE I.

Distance of the piston from the termination of its stroke, when the steam is cut off, in parts of the length of its stroke - - - -	$\frac{8}{24}$ or $\frac{1}{3}$	$\frac{7}{24}$	$\frac{6}{24}$ or $\frac{1}{4}$	$\frac{5}{24}$	$\frac{4}{24}$ or $\frac{1}{6}$	$\frac{3}{24}$ or $\frac{1}{8}$	$\frac{2}{24}$ or $\frac{1}{12}$	$\frac{1}{24}$
Cover on the steam side of the valve, in decimal parts of the length of its stroke -	·289	·270	·250	·228	·204	·177	·144	·102

This table, as we have already intimated, is computed on the supposition that the valve is to have no lead; but, if it is to have lead, all that is necessary is, to subtract half the proposed lead from the cover found from the table, and the remainder will be the proper quantity of cover to give to the valve. Suppose that, in the last example, the valve was to have $\frac{1}{4}$ inch of lead, we would subtract $\frac{1}{8}$ inch from the 5 inches found for the cover by the table: that would leave $4\frac{7}{8}$ inches for the quantity of cover that the valve ought to have.

TABLE II.

Length of the stroke of the valve in inches.	Cover required on the steam side of the valve to cut the steam off at any of the under-noted parts of the stroke.							
	$\frac{1}{3}$	$\frac{7}{24}$	$\frac{1}{4}$	$\frac{5}{24}$	$\frac{1}{6}$	$\frac{1}{8}$	$\frac{1}{12}$	$\frac{1}{24}$
24	6·94	6·48	6·00	5·47	4·90	4·25	3·47	2·45
$23\frac{1}{2}$	6·79	6·34	5·88	5·36	4·79	4·16	3·39	2·39
23	6·65	6·21	5·75	5·24	4·69	4·07	3·32	2·34
$22\frac{1}{2}$	6·50	6·07	5·62	5·13	4·59	3·98	3·25	2·29
22	6·36	5·94	5·50	5·02	4·49	3·89	3·13	2·24
$21\frac{1}{2}$	6·21	5·80	5·38	4·90	4·39	3·80	3·10	2·19
21	6·07	5·67	5·25	4·79	4·28	3·72	3·03	2·14
$20\frac{1}{2}$	5·92	5·53	5·12	4·67	4·18	3·63	2·96	2·09
20	5·78	5·40	5·00	4·56	4·08	3·54	2·89	2·04
$19\frac{1}{2}$	5·64	5·26	4·87	4·45	3·98	3·45	2·82	1·99
19	5·49	5·13	4·75	4·33	3·88	3·36	2·74	1·94
$18\frac{1}{2}$	5·34	4·99	4·62	4·22	3·77	3·27	2·67	1·88
18	5·20	4·86	4·50	4·10	3·67	3·19	2·60	1·83
$17\frac{1}{2}$	5·06	4·72	4·37	3·99	3·57	3·10	2·53	1·78
17	4·91	4·59	4·25	3·88	3·47	3·01	2·45	1·73
$16\frac{1}{2}$	4·77	4·45	4·12	3·76	3·36	2·92	2·38	1·68
16	4·62	4·32	4·00	3·65	3·26	2·83	2·31	1·63
$15\frac{1}{2}$	4·48	4·18	3·87	3·53	3·16	2·74	2·24	1·58
15	4·33	4·05	3·75	3·42	3·06	2·65	2·16	1·03
$14\frac{1}{2}$	4·19	3·91	3·62	3·31	2·96	2·57	2·09	1·48
14	4·05	3·78	3·50	3·19	2·86	2·48	2·02	1·43
$13\frac{1}{2}$	3·90	3·64	3·37	3·08	2·75	2·39	1·95	1·37
13	3·76	3·51	3·25	2·96	2·65	2·30	1·88	1·32
$12\frac{1}{2}$	3·61	3·37	3·12	2·85	2·55	2·21	1·80	1·27
12	3·47	3·24	3·00	2·74	2·45	2·12	1·73	1·22
$11\frac{1}{2}$	3·32	3·10	2·87	2·62	2·35	2·03	1·66	1·17
11	3·18	2·97	2·75	2·51	2·24	1·95	1·58	1·12
$10\frac{1}{2}$	3·03	2·83	2·62	2·39	2·14	1·86	1·51	1·07
10	2·89	2·70	2·50	2·28	2·04	1·77	1·44	1·02
$9\frac{1}{2}$	2·65	2·56	2·37	2·17	1·93	1·68	1·32	·96
9	2·60	2·43	2·25	2·05	1·84	1·59	1·30	·92
$8\frac{1}{2}$	2·46	2·29	2·12	1·94	1·73	1·50	1·23	·86
8	2·31	2·16	2·00	1·82	1·63	1·42	1·15	·81
$7\frac{1}{2}$	2·16	2·02	1·87	1·71	1·53	1.33	1·08	·76
7	2·02	1·89	1·75	1·60	1·43	1·24	1·01	·71
$6\frac{1}{2}$	1·88	1·75	1·62	1·48	1·32	1·15	·94	·66
6	1·73	1·62	1·50	1·37	1·22	1·06	·86	·61
$5\frac{1}{2}$	1·58	1·48	1·37	1·25	1·12	·97	·79	·56
5	1·44	1·35	1·25	1·14	1·02	·88	·72	·51
$4\frac{1}{2}$	1·30	1·21	1·12	1·03	·92	·80	·65	·46
4	1·16	1·08	1·00	·91	·82	·71	·58	·41
$3\frac{1}{2}$	1·01	·94	·87	·80	·71	·62	·50	·35
3	·86	·81	·75	·68	·61	·53	·44	·30

Table II. is an extension of Table I., for the purpose of obviating, in most cases, the necessity of even the very small degree of trouble required in multiplying the stroke of the valve by one of the decimals in Table I. The first line of Table II. consists, as in Table I., of eight fractions, indicating the various parts of the stroke at which the steam may be cut off. The first column on the left hand consists of various numbers that represent the different lengths that may be given to the stroke of the valve, diminishing, by half-inches, from 24 inches to 3 inches. Suppose that you wish the steam cut off at any of the eight parts of the stroke indicated in the first line of the table (say at $\frac{1}{8}$ from the end of the stroke,) you find $\frac{1}{8}$ at the top of the sixth column from the left. Look for the proposed length of stroke of the valve (say 17 inches) in the first column on the left. From 17, in that column, run along the line towards the right, and in the sixth column, and directly under the $\frac{1}{8}$ at the top, you will find 3·47, which is the cover required to cause the steam to be cut off at $\frac{1}{8}$ from the end of the stroke, if the valve has no lead. If you wish to give it lead (say $\frac{1}{4}$ inch,) subtract the half of that, or $\frac{1}{8}$ = ·125 inch from 3·47, and you will have 3·47 — ·125 = 3·345 inches, the quantity of cover that the valve should have.

To find the greatest breadth that we can give to the port in this case, we have, as before, half the length of stroke, $8\frac{1}{2}$ — 3·345 = 5·155 inches, which is the greatest breadth we can give to the port with this length of stroke. It is scarcely necessary to observe that it is not at all essential that the port should be so broad as this; indeed, where great length of stroke in the valve is not inconvenient, it is always an advantage to make it travel farther than is just necessary to make the port full open; because, when it travels further, both the exhausting and steam ports are more quickly opened, so as to allow greater freedom of motion to the steam.

The manner of using this table is so simple, that we need not trouble the reader with more examples. We pass on, therefore, to explain the use of Table III.

Suppose that the piston of a steam-engine is making its downward stroke, that the steam is entering the upper part of the cylinder by the upper steam-port, and escaping from below the piston by the lower exhausting-port; then, if (as is generally the case) the slide-valve has some cover on the steam side, the upper port will be closed before the piston gets to the bottom of the stroke, and the steam above then acts expansively, while the communication between the bottom of the cylinder and the condenser still continues open, to allow any vapour from the condensed water in the cylinder, or any leakage past the piston, to escape into the condenser; but, before the piston gets to the bottom of the cylinder, this passage to the condenser will also be cut off by the valve closing the lower port. Soon after the lower port is thus closed, the upper port will be opened towards the condenser, so as to allow the steam that has been acting expansively to escape. Thus, before the piston has completed its stroke, the propelling power is removed from behind it, and a resisting power is opposed before it, arising from the vapour in the cylinder, which has no longer any passage open to the condenser. It is evident, that if there is no cover on the exhausting side of the valve, the exhausting port before the piston will be closed, and the one behind it opened, at the same time; but, if there is any cover on the exhausting side, the port before the piston will be closed before that behind it is opened; and the interval between the closing of the one, and the opening of the other, will depend on the quantity of cover on the exhausting side of the valve. Again, the position of the piston in the cylinder, when these ports are closed and opened respectively, will depend on the quantity of cover that the valve has on the steam side. If the cover is large enough to cut the steam off when the piston is yet a considerable distance from the end of its stroke, these ports will be closed and opened at a proportionably early part of the stroke; and when it is attempted to obtain great expansion by the slide-valve alone, without an expansion-valve, considerable loss of power is incurred from this cause.

Table III. is intended to show the parts of the stroke where, under any given arrangement of slide-valve, these ports close and open respectively, so that thereby the engineer may be able to estimate how much of the efficiency of the engine he loses, while he is trying to add to the power of the steam by increasing the expansion in this manner. In the table, there are eight double columns, and at the heads of these columns are eight fractions as before, representing so many different parts of the stroke at which the steam may be supposed to be cut off.

In the left-hand single column in each double one, are four decimals which represent the distance of the piston (in terms of the length of its stroke) from the end of its stroke when the exhausting-port before it is opened, corresponding with the degree of expansion indicated by the fraction at the top of the double column and the cover on the exhausting side opposite to these decimals respectively in the left-hand column. The right-hand single column in each double one contains also each four decimals, which show in the same way at what part of the stroke the exhausting-port behind the piston is opened. A few examples will, perhaps, explain this best.

Suppose we have an engine in which the slide-valve is made to cut the steam off when the piston is 1-3d from the end of its stroke, and that the cover on the exhausting side of the valve is 1-8th of the whole length of its

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* By the "breadth" of the port, we mean its dimension in the direction of the valve's motion; in short, its perpendicular depth when the cylinder is upright. The words "cover" and "lap" are synonymous.

TABLE III

Cover on the exhausting side of the valve in parts of the length of its stroke.	Steam cut off at 1-3d from the end of the stroke.		Steam cut off at 7-24ths from the end of the stroke.		Steam cut off at 1-4th from the end of the stroke.		Steam cut off at 5-24ths from the end of the stroke.		Steam cut off at 1-6th from the end of the stroke.		Steam cut off at 1-8th from the end of the stroke.		Steam cut off at 1-12th from the end of the stroke.		Steam cut off at 1-24th from the end of the stroke.	
	Distance of the piston from the end of its stroke, when the exhausting-port before it is shut (in parts of the stroke).	Distance of the piston from the end of its stroke, when the exhausting-port behind it is opened (in parts of the stroke).	Distance of the piston from the end of its stroke, when the exhausting-port before it is shut (in parts of the stroke).	Distance of the piston from the end of its stroke, when the exhausting-port behind it is opened (in parts of the stroke).	Distance of the piston from the end of its stroke, when the exhausting-port before it is shut (in parts of the stroke).	Distance of the piston from the end of its stroke, when the exhausting-port behind it is opened (in parts of the stroke).	Distance of the piston from the end of its stroke, when the exhausting-port before it is shut (in parts of the stroke).	Distance of the piston from the end of its stroke, when the exhausting-port behind it is opened (in parts of the stroke).	Distance of the piston from the end of its stroke, when the exhausting-port before it is shut (in parts of the stroke).	Distance of the piston from the end of its stroke, when the exhausting-port behind it is opened (in parts of the stroke).	Distance of the piston from the end of its stroke, when the exhausting-port before it is shut (in parts of the stroke)	Distance of the piston from the end of its stroke, when the exhausting-port behind it is opened (in parts of the stroke)	Distance of the piston from the end of its stroke, when the exhausting-port before it is shut (in parts of the stroke).	Distance of the piston from the end of its stroke, when the exhausting-port behind it is opened (in parts of the stroke).	Distance of the piston from the end of its stroke, when the exhausting-port before it is shut (in parts of the stroke)	Distance of the piston from the end of its stroke, when the exhausting-port behind it is opened (in parts of the stroke).
1-8th	·178	·033	·161	·026	·143	·019	·126	·012	·109	·008	·093	·004	·074	·001	·053	·001
1-16th	·130	·060	·118	·052	·100	·040	·085	·030	·071	·022	·058	·015	·043	·008	·027	·002
1-32d	·113	·073	·101	·066	·085	·051	·069	·042	·053	·033	·043	·023	·033	·013	·024	·004
0	·092	·092	·082	·082	·067	·067	·055	·055	·043	·043	·033	·033	·022	·022	·011	·011

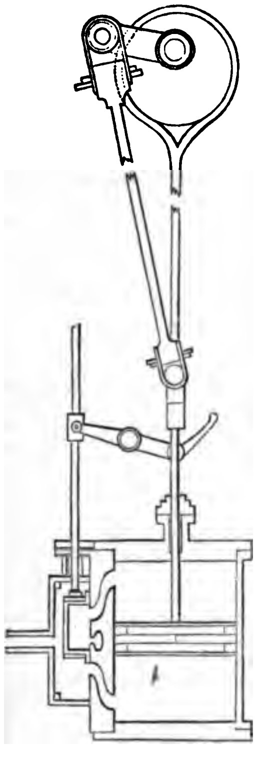
stroke. Let the stroke of the piston be 6 feet, or 72 inches. We wish to know when the exhausting port before the piston will be closed, and when the one behind it will be opened. At the top of the left-hand double column, the given degree of expansion (1–3d) is marked, and in the extreme left column we have at the top the given amount of cover (1-8th). Opposite the 1-8th, in the first double column, we have ·178 and ·033, which decimals, multiplied respectively by 72, the length of the stroke, will give the required positions of the piston : thus 72 × ·178 = 12·8 inches = distance of the piston from the end of the stroke when the exhausting port *before* the piston is shut: and 72 × ·033 = 2·38 inches = distance of the piston from the end of its stroke when the exhausting-port behind it is opened.

To take another example. Let the stroke of the valve be 16 inches, the cover on the exhausting side ½ inch, the cover on the steam side 3¼ inches, the length of the stroke of the piston 60 inches. It is required to ascertain all the particulars of the working of this valve. The cover on the exhausting side is evidently $\frac{1}{32}$ of the length of the valve stroke. Again, looking at 16 in the left-hand column of Table II., we find in the same horizontal line 3·26, or very nearly 3¼ under ⅙ at the head of the column, thus showing that the steam will be cut off at ⅙ from the end of the stroke. Again, under ⅙ at the head of the fifth double column from the left in Table III., and in a horizontal line with $\frac{1}{32}$ in the left-hand column, we have ·053 and ·033. Hence, ·053 × 60 = 3·18 inches = distance of the piston from the end of its stroke when the exhausting port before it is shut, and ·033 × 60 = 1·98 inches = distance of the piston from the end of its stroke when the exhausting port behind it is opened. If in this valve the cover on the exhausting side were increased (say to 2 inches, or ⅛ of the stroke,) the effect would be to make the port before the valve be shut sooner in the proportion of ·109 to ·053, and the port behind it later in the proportion of ·008 to ·033 (see Table III.). Whereas, if the cover on the exhausting side were removed entirely, the port before the piston would be shut and that behind it opened at the same time, (and see bottom of fifth double column, Table III.) the distance of the piston from the end of its stroke at that time would be ·043 × 60 = 2·58 inches.

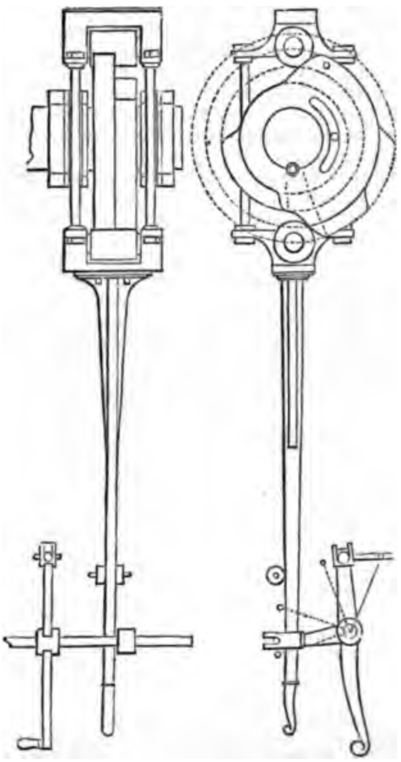
An inspection of Table III. shows us the effect of increasing the expansion by the slide-valve in augmenting the loss of power occasioned by the imperfect action of the eduction passages. Referring to the bottom line of the Table, we see that the eduction passage before the piston is closed, and that behind it opened, (thus destroying the whole moving power of the engine,) when the piston is ·092 from the end of its stroke, the steam being cut off at ⅓ from the end. Whereas, if the steam is only cut off at $\frac{1}{24}$ from the end of the stroke, the moving power is not withdrawn till only ·011 of the stroke remains uncompleted. It will also be observed that increasing the cover on the exhausting side has the effect of retaining the action of the steam longer *behind* the piston, but it at the same time causes the eduction port *before* it to be closed sooner.

A very cursory examination of the action of the slide-valve is sufficient to show that the cover on the steam side should always be greater than on the exhausting side. If they are equal, the steam would be admitted on one side of the piston at the same time that it was allowed to escape from the other; but universal experience has shown that when this is the case a very considerable part of the power of the engine is destroyed by the resistance opposed to the piston, by the exhausting steam not getting away to the condenser with sufficient rapidity. Hence we see the necessity of the cover on the exhausting side being always less than the cover on the steam side; and the difference should be the greater the higher the velocity of the piston is intended to be, because the quicker the piston moves the passage for the waste steam requires to be the larger, so as to admit of its getting away to the condenser with as great rapidity as possible. In locomotive or other engines, where it is not wished to expand the steam in the cylinder at all, the slide-valve is sometimes made with very little cover on the steam side: and in these circumstances, in order to get a sufficient difference between the cover on the steam and exhausting sides of the valve, it may be necessary not only to take away all the cover on the exhausting side, but to take off still more, so as to make both exhausting passages be, in some degree, open, when the valve is at the middle of its stroke. This, accordingly, is sometimes done in such circumstances as we have described; but, when there is even a small degree of cover on the steam side, this plan of taking *more than all* the cover off the exhausting

Fig. 162.



Figs. 163, 164.



side ought never to be resorted to, as it can serve no good purpose, and will materially increase an evil we have already explained; viz. the opening of the exhausting-port behind the piston before the stroke is nearly completed. The Tables apply equally to the common short slide three-ported valves and to the long D valves.

In *fig.* 162. is exhibited a common arrangement of the valves in locomotive engines, and in *figs.* 163. and 164. are shown an arrangement for working valves by a shifting cam, by which the amount of expansion may be varied. This particular arrangement however is antiquated, and is now but little used.

The extent to which expansion can be carried beneficially by means of lap upon the valve is about one-third of the stroke; that is, the valve may be made with so much lap, that the steam will be cut off when one-third of the stroke has been performed, leaving the residue to be accomplished by the agency of the expanding steam; but if more lap be put on than answers to this amount of expansion, a very distorted action of the valve will be produced, which will impair the efficiency of the engine. If a further amount of expansion than this is wanted, it may be accomplished by wire-drawing the steam, or by so contracting the steam passage, that the pressure within the cylinder must decline when the speed of the piston is accelerated, as it is about the middle of the stroke. Thus, for example, if the valve be so made as to shut off the steam by the time two-thirds of the stroke have been performed, and the steam be at the same time throttled in the steam pipe, the full pressure of the steam within the cylinder cannot be maintained except near the beginning of the stroke where the piston travels slowly; for as the speed of the piston increases, the pressure necessarily subsides, until the piston approaches the other end of the cylinder, where the pressure would rise again but that the operation of the lap on the valve by this time has had the effect of closing the communication between the cylinder and steam pipe, so as to prevent more steam from entering. By throttling the steam, therefore, in the manner here indicated, the amount of expansion due to the lap may be doubled, so that an engine with lap enough upon the valve to cut off the steam at two-thirds of the stroke, may, by the aid of wire-drawing, be virtually rendered capable of cutting off the steam at one-third of the stroke. The usual manner of cutting off the steam, however, is by means of a separate valve, termed an expansion valve; but such a device appears to be hardly necessary in many engines. In the Cornish engines, where the steam is cut off in some cases at one-twelfth of the stroke, a separate valve for the admission of steam, other than that which permits its escape, is of course indispensable; but in common rotative engines, which may realise expansive efficacy by throttling, a separate expansive valve does not appear to be required. In all engines there is a point beyond which expansion cannot be carried with advantage, as the resistance to be surmounted by the engine will then become equal to the impelling power; but in engines working with a high pressure of steam that point is not so speedily attained.

In high pressure, as contrasted with condensing engines, there is always the loss of the vacuum, which will generally amount to 12 or 13 lbs. on the square inch, and in high pressure engines, there is a benefit arising from the use of a very high pressure over a pressure of a moderate account. In all high pressure engines, there is a diminution in the power caused by the counteracting pressure of the atmosphere on the educting side of the piston: for the force of the piston in its descent would obviously be greater, if there was a vacuum beneath it; and the counteracting pressure of the atmosphere is relatively less when the steam used is of a very high pressure. It is clear, that if we bring down the pressure of the steam in a high pressure engine to the pressure of the atmosphere, it will not exert any power at all, whatever quantity of steam may be expended, and if the pressure be brought nearly as low as that of the atmosphere, the engine will exert only a very small amount of power; whereas, if a very high pressure be employed, the pressure of the atmosphere will become relatively as small in counteracting the impelling pressure, as the attenuated vapour in the condenser of a condensing engine is in resisting the lower pressure which is there employed. Setting aside loss from friction, and supposing the vacuum to be a perfect one, there would be no benefit arising from the use of steam of a high pressure in condensing engines, for the same weight of steam used without expansion, or with the same measure of expansion, would produce at every pressure the same amount of mechanical power. A piston, with a square foot of area, and a stroke of three feet with a pressure of one atmosphere, would obviously lift the same weight through the same distance, as a cylinder with half a square foot of area, a stroke of three feet, and a pressure of two atmospheres. In the one case, we have three cubic feet of steam of the pressure of one atmosphere, and in the other case 1$\frac{1}{2}$ cubic feet of the pressure of two atmospheres. But there is the same weight of steam, or the same quantity of heat and water in it, in both cases, so that it appears a given weight of steam would, under such circumstances, produce a definite amount of power, without reference to the pressure. In the case of ordinary engines, however, these conditions do not exactly apply; the vacuum is not a perfect one, and the pressure of the resisting vapour becomes relatively greater as the pressure of the steam is diminished; the friction also becomes greater from the necessity of employing larger cylinders, so that even in the case of condensing engines, there is a benefit arising from the use of steam of a considerable pressure. Expansion cannot be carried beneficially to any great extent, unless the initial pressure be considerable; for if steam of a low pressure were used, the ultimate tension would be reduced to a point so nearly approaching that of the vapour in the condenser, that the difference would not suffice to overcome the friction of the piston; and a loss of power would be occasioned by carrying expansion to such an extent. In some of the Cornish engines, the steam is cut off at one-twelfth of the stroke; but there would be a loss arising from carrying the expansion so far, instead of a gain, unless the pressure of the steam were considerable. It is clear, that in the case of engines which carry expansion very far, a very perfect vacuum in the condenser is more important than it is in other cases. Nothing can be easier than to compute the ultimate pressure of expanded steam, so as to see at what point expansion ceases to be productive of benefit; for as the pressure of expanded steam is inversely as the space occupied, the terminal pressure when the expansion is twelve times is just one-twelfth of what it was at first, and so on, in all other projections. The total pressure should be taken as the initial pressure—not the pressure on the safety-valve, but that pressure plus the pressure of the atmosphere.

In high pressure engines working at from 70 to 90 lbs. on the square inch, as in the case of locomotives, the efficiency of a given quantity of water raised into steam may be considered to be about the same as in condensing engines. If the pressure of steam in a high pressure engine be 120 lbs., or 125 lbs. above the atmosphere, then the resistance occasioned by the atmosphere will cause a loss of $\frac{1}{8}$th of the power. If the pressure of the steam in a low pressure engine be 16 lbs. on the square inch, or 11 lb. above the atmosphere, and the tension of the vapour in the condenser be equivalent to 4 inches of mercury, or 2 lbs. of pressure on the square inch, then the resistance occasioned by this rare vapour will also cause a loss of $\frac{1}{8}$th of the power. A high pressure engine, therefore, with a pressure of 105 lbs. above the atmosphere, works with only the same loss from resistance to the piston, as a low pressure engine with a pressure of 1 lb. above the atmosphere, and with these proportions the power produced by a given weight of steam will be the same, whether the engine be high pressure or condensing.

SPHEROIDAL CONDITION OF WATER IN BOILERS.

Some of the more prominent causes of boiler explosions have been already enumerated; but explosions have in some cases been attributed to the spheroidal condition of the water in the boiler, consequent upon the flues becoming red hot from a deficiency of water, the accumulation of scale, or otherwise. The attachment of scale, from its imperfect conducting power, will cause the iron to be unduly heated; and if the scale be accidentally detached, a partial explosion may occur in consequence. It is found, that a sudden disengagement of steam does not immediately follow the contact of water with the hot metal, for water thrown upon red-hot iron is not immediately converted into steam, but assumes the spheroidal form and rolls about in globules over the surface. These globules, however high the temperature of the metal may be on which they are placed, never rise above the temperature of 205°, and give off but very little steam; but if the temperature of the metal be lowered, the water ceases to retain the spheroidal form, and comes into intimate contact with the metal, whereby a rapid disengagement of steam takes place. If water be poured into a very hot copper flask, the flask may be corked up, as there will be scarce any steam produced so long as the high temperature is maintained; but so soon as the temperature is suffered to fall below 350° or 400°, the spheroidal condition being no longer maintainable, steam is generated with rapidity, and the cork will be projected from the mouth of the flask with great force. In a boiler, no doubt, where there is a considerable head of water, the repellant action of the spheroidal globules will be more effectually counteracted than in the small vessels employed in experimental researches. But it is doubtful whether in all boilers there may not be something of the spheroidal action perpetually in operation, and leading to effects at present mysterious or inexplicable.

One of the most singular phenomena attending the spheroidal condition is, that the vapour arising from a spheroid is of a far higher temperature than the spheroid itself. Thus, if a thermometer be held in the atmosphere of vapour which surrounds a spheroid of water, the mercury instead of standing at 205°, as would be the case if it had been immersed in the spheroid, will rise to a point determinable by the temperature of the vessel in which the spheroid exists. In the case of a spheroid, for example, existing within a crucible raised to a temperature of 400°, the thermometer, if held in the vapour, will rise to that point; and if the crucible be made red hot the thermometer will be burst, from the boiling point of mercury having been exceeded. A part of this effect may, indeed, be traced to direct radiation, yet it appears indisputable from the experiments which have been made, that the vapour of a liquid spheroid is much hotter than the spheroid itself.

MISCELLANEOUS REMARKS UPON BOILERS.

In the well-known steam vessels Her Majesty and Royal Consort, the boilers supply a pair of engines with steam, the cylinders of which are 65 inches in diameter, and the stroke 5 feet 6 inches. There are four boilers in each vessel fired at opposite ends, 13 inches separate in the direction of the vessel's length, and 2 feet 6 inches asunder athwart-ships. The flues of the four boilers join so as to form the foot of the funnel, which is 5 feet 6 inches in diameter. The water-space at the inner side of each boiler is also secured by four two-inch bolts. Each boiler has three furnaces, the centre one being 2 feet 2 inches wide and the side ones 2 feet 4½ inches on the outside, but widening within to 2 feet 4 inches, and 2 feet 6 inches respectively. This is a very well secured boiler, but it would be an improvement if the tubes were placed at a slight inclination, in order to facilitate the disengagement of the steam from the aftermost tube plate.

The durability of boilers is affected by many circumstances, the more prominent of which it may be expedient to enumerate. In marine boilers the steam-chests and the ash-pits of the furnaces are the first parts to give way. The outside of the steam-chest is worn away by the dripping of water from the deck, and the inside by the action of the steam, while the wear of the ash-pits is chiefly attributable to the practice of wetting the ashes and quenching the fires with salt water. The action of the steam upon the interior of the steam-chest is most capricious, some parts being worn away rapidly, while other parts are uninjured, and the parts most rapidly deteriorated in one boiler are often untouched in another. The iron of the steam-chest, however, is as a general rule most rapidly worn away in those boilers in which scale is permitted to accumulate, which may perhaps be from the extrication of muriatic acid from the salt. Painting the insides of boilers is not of much use as a preservative from corrosion, and is said to induce priming; but we think a whitewash, if it may so be termed, of Roman cement applied in several successive coats to the interior of the steam-chest, would be found to be an effectual preservative of the iron in that situation. For protecting the outsides of boilers we know of no more effectual method than felting them and covering them afterwards with sheet lead that is soldered wherever there is a joining. The application of felt, however, to the outside of boilers has in some cases been found to accelerate their corrosion in the inside; but the inside corrosion may be obviated by the application of the Roman cement.

Steam-pipes, whether made of iron or copper, are attended with practical objections. Malleable iron pipes become rapidly corroded by the passage of the steam, and large flakes of hard rust are carried into the valve and cylinder, where they work much damage by scratching into ruts the surfaces that ought to be steam-tight. Copper steam-pipes have a galvanic action upon the cylinder faces and the valves, by which the iron is worn away or turned into plumbago. Copper pipes, however, are upon the whole less objectionable than pipes made of iron, and should obtain a preference, though we think it likely that the recent reductions of the duty on glass will lead to the manufacture of pipes enamelled on the inside, which will be greatly superior to those now in use, as they will obviate the evil of corrosion.

All tubular boilers should be provided with a self-acting contrivance for maintaining the feed, and this contrivance should be put in connexion with a small engine whose functions it is to supply the boilers with water. By this expedient the water level may be maintained at its proper height, even when the engine is stationary, without having recourse to the laborious operation of pumping by hand. In a steam vessel a small engine may be applied to a number of useful purposes, besides that of feeding the boiler, such as raising the anchor and transferring the coal from one part of the vessel to another.

We have long been of opinion, that although there may not be much prospect of increasing the economy of the present steam engine by obviating sources of waste not yet recognised, yet that the steam engine is not the best conceivable instrument for obtaining the mechanical power due to a certain quantity of heat. It is only where two different temperatures subsist that mechanical power can be realised, and the farther removed these temperatures are from one another the greater the resulting power must be. That instrument will therefore realise the greatest mechanical effect from a given quantity of heat, which may be worked with the greatest extremes of temperature; and if steam could be employed for working an engine as hot, or nearly as hot, as the fire by which it is generated, the true mechanical effect due to the heat employed would be obtained; but as this obviously cannot be done, there is a loss incidental to the use of the steam engine which other contrivances may be invented to avert. In any case that we can imagine there must be much difficulty in dealing with the high temperatures this principle appears to prescribe, but the principle does not make high temperatures imperative, but merely great differences of temperature; and very low temperatures may not present the same impediments as very high ones. It is not by steam, however, that the benefits due to great differences of temperature are likely to be realised, but by some other agent, that will be better adapted to the new circumstances in which it is placed.

Surcharged steam.—Surcharged steam is steam to which an additional dose of heat has been given after leaving the water, and its temperature is therefore higher than is represented by its elastic force. If from ordinary steam any part of the heat be abstracted, a portion of the steam must be condensed, but some of the heat may be abstracted from surcharged steam without occasioning condensation, and it is therefore spoken of as overcharged with heat, or in other words possessed of more heat than is requisite for maintaining the vaporous form. Much difference of opinion exists as to whether the use of surcharged steam in steam engines is beneficial. The principle we have just mentioned appears to favour the notion that it is, but the general impression among engineers is, that the use of surcharged steam is attended with no advantage. We cannot say we concur in this belief; and as some vindication of our nonconformity, we shall here give from the *Artizan* some computations which favour the impression that surcharged steam is productive of an economy in fuel:—

(1.) When air is heated it expands, and the increments of volume are proportional to the increments of temperature. Every increment of 1° in temperature produces an increase in volume of $\frac{1}{480}$th part of the bulk of the air at 32°. This rule has been found to apply to steam out of contact with water.

(2.) The specific heat of steam out of contact with water is in this case supposed to be inversely as its specific gravity. The specific heat of steam at 212° $= {\cdot}847$.

From these data we may determine the amount of the saving by using the steam surcharged with heat after leaving the boiler. The subject may be investigated as follows; and we may suppose the temperature of the steam to be 212°:

Let t' = temperature to which the steam is raised out of contact with water.

Let s = mean specific heat of the steam between the temperatures 212° and t'.

Let v = the volume of steam at the temperature t', the volume at 212° being 100.

Let x = the volume of the same weight of steam at 32°, supposing that it could be cooled to 32° without condensing.

Let h = heat required to raise 100 volumes of steam from 212° to t'.

Let b = weight of water in 100 volumes of steam at 212°.

Let c = heat required to raise the temperature of a quantity of water ($=b$), 1 degree.

Let h' = heat required to generate, from water at 60°, a quantity of steam equal in volume to $v-100$.

From (1) we have $x+x\times\frac{1}{450}(212-32)=100$; or, since $\frac{1}{480}={\cdot}002083$

$$x+x\times{\cdot}002083\times180=100\ \therefore x\,(1+{\cdot}37494)=100.$$

$$\therefore x=\frac{100}{1{\cdot}37494}.$$

From (1) also we get $v=100+x\times{\cdot}002083\,(t'-212)$, which by substituting the value of x previously found becomes

$$v=100+\frac{{\cdot}2083\,(t'-212)}{{\cdot}37494}.$$

Since the specific heat of steam at 212° is ·847, and since we have supposed it to vary inversely as the specific gravity $100 : v :: {\cdot}847$: specific heat at the temperature t', which is therefore $\frac{{\cdot}847\,v}{100}$; hence we have

$$s=\tfrac{1}{2}\left(\frac{{\cdot}847\,v}{100}+{\cdot}847\right);$$

Or, substituting the value of v,

$$s=\tfrac{1}{2}\left({\cdot}847+\frac{001764\,(t'-212)}{1{\cdot}37494}+{\cdot}847\right)$$

$$={\cdot}847+\frac{000882\,(t'-212)}{1{\cdot}37494}.$$

But $h=(t'-212^\circ).\,s.\,c$, which, by substituting the value of s, becomes

$$h=\left\{{\cdot}847\,(t'-212)+\frac{000882\,(t'-212)^2}{1{\cdot}37494}\right\}.c.$$

Now the addition to the volume of steam produced by heating it from 212° to $t'=v-100=\frac{{\cdot}2083\,(t'-212)}{1{\cdot}37494}$, and the water in an equal volume may be found by this proportion.

$$100 : b :: \frac{{\cdot}2083\,(t'-212)}{1{\cdot}37494} : \frac{{\cdot}002083\,(t'-212)\,.b}{1{\cdot}37494}=\text{weight of water}$$

in a quantity of steam whose volume is at 212° $v-100$. Hence, supposing the latent heat of steam to be 1000°, we have

$$h=(1000+150)\,.c\times\frac{002083\,(t'-212)}{1{\cdot}37494}=\frac{2{\cdot}3954\,(t'-212)\,.c}{1{\cdot}37494}.$$

Now, since h = heat required to produce an additional volume of steam equal to $v-100$ by heating the steam out of contact with water, and since h' equals the heat required to make the same addition to the volume of the steam by generating it from water, it follows that the saving of heat by using the former method is $h'-h$.

$$=\frac{2{\cdot}3954\,(t'-212)\,.c}{1{\cdot}37494}-\left\{{\cdot}847\,(t'-212)+\frac{{\cdot}000682\,(t'-212)^2}{1{\cdot}37494}\right\}.c,$$

which, reduced,

$$=\frac{1{\cdot}2308\,(t'-212)-000882\,(t-212)^2\,.c}{1{\cdot}37494}$$

The weight of water in steam equal in volume to v at 212° is evidently $b.\frac{v}{100}$, consequently the heat required to generate from water steam equal in volume to *v*, is $\dot{b}\,\frac{v}{100}$, $\frac{1150}{b}\,c$, which, by substituting the value of *b*, becomes

$$1500\left(1+\frac{00283\,(t'-212)}{1{\cdot}37494}\right)c,$$

which, being reduced, gives the whole heat required to raise steam equal in volume to *v* from water

$$\frac{=1581{\cdot}181+2{\cdot}3954\,(t'-212)}{1{\cdot}37494}.c.$$

Consequently by this formula the heat saved is expressed in parts of the whole heat used in generating steam in the usual way,

$$h'-h.\ \frac{1{\cdot}37494}{1581{\cdot}181+2{\cdot}3954\,(t'-212)}\cdot\frac{1}{c}\text{ by substitution becomes}$$

$$\frac{1{\cdot}2308\,(t'-212)-000882\,(t'-212)^2}{1581{\cdot}181+2{\cdot}3954\,(t'-212)}$$

If the steam be heated to 600°, then $t'=600°$, and the formula in such case gives the saving equal to $\frac{1}{7{\cdot}2}$ of the heat used, or fuel consumed in the common way. In a similar manner the saving may easily be calculated for any other value of t'.

The preceding investigation is founded on the assertion that the specific heat varies inversely as the temperature; and supposing such to be the case, the saving resulting from heating the steam to 600° after leaving the boiler would be about $\frac{1}{7}$th of the whole fuel used. I shall next suppose that the specific heat *does not* vary with the temperature, but that during expansion a certain quantity of heat becomes latent, in which case the sum of the sensible and latent heats absorbed by the steam after leaving the boiler (its pressure being the same), multiplied by the specific heat, will give the actual quantity of heat added to the steam in very simple terms.

From numerous experiments by Leslie and Dalton, on the heat or cold produced by air during, compression or expansion, Mr. Leslie has deduced the following very simple formula:—

If θ denote the density of the air, then $45\left(\frac{1}{\theta}-\theta\right)$ will denote the number of degrees of cold produced when the air is rarefied to unity, or it will represent the heat that requires to be added so as to keep the temperature unchanged during expansion. The latent heat of steam is about 1000°, wherefore the heat necessary to raise water from 60° into steam is 1000° + 152 = 1152°, Fahrenheit. Let us suppose, as before, that the steam after leaving the water at the temperature of 212° is heated to 600°, and at the same time that its pressure remains unaltered. As the specific heat of steam, as determined by the most accurate experiments, is ·847, that of water being 1·000, the accession of heat necessary to raise steam from 212° to 600° would be 328° if there were no expansion or alteration of volume;

for 1 : 388 : : ·847 : 328.

Supposing the steam to be allowed to expand as the law of expansion is $\frac{1}{480}$ part of its bulk at 32° for each degree of temperature (See Thomson on Heat, p. 9), 100 volumes at 212° become when heated to 600° = 159 volumes.

$$\left.\begin{array}{l}448+212=\ \ 660\\448+600=1048\end{array}\right\}660:1048::100:158{\cdot}8\text{ or }159.$$

The density of the steam when so expanded will be

$\frac{100}{159}=\cdot629$; therefore $45\left(\frac{1}{\cdot629}-\cdot629\right)$ = the heat absorbed by air during its expansion from 100 to 159 volumes,

$$45\left(\frac{1}{\cdot629}-\cdot629\right)=45\left(\frac{1}{\cdot629}-\frac{\cdot629^2}{\cdot629}\right)=45\left(\frac{1}{\cdot629}-\frac{\cdot401641}{\cdot629}\right)=45\ (\cdot598359)$$

$= 26{\cdot}025015$ degrees.

As the specific heat of steam, however, is greater than that of air, the heat necessary to maintain the temperature of steam during its expansion from 100 to 159 volumes will be 82°. For ·2669 : 26 : : ·847 : 82°; therefore the total heat required to convert 100 volumes of steam into 159 volumes is 1152° + 328° + 82° = 1562°, the pressure of the steam being supposed to be unaltered.

To raise 159 volumes of steam in the common way would require 1831·68°. For 100 : 1152 : : 159 : 1831·68°; wherefore 1831·68 − 1562 = 270° = the saving resulting from the expansion of the steam by heat after it has been generated, $1832\div270=\frac{1}{6{\cdot}7}$ of the whole fuel used, instead of $\frac{1}{7.2}$, as determined by the previous method.

Expansion. — We have already, at page 12., given some explanation of the principle of working an engine expansively, by which method we showed a large economy of fuel may be realised; and at page 25. we have given a table of hyperbolic or Neperian logarithms, for the purpose of facilitating computations upon this subject.

Let the pressure of the steam in the boiler be expressed by unity, and let x represent the space through which the piston has moved whilst urged by the expanding steam. The density will then be $\frac{1}{1+x}$ and assuming that the densities and elasticities are proportionate, $\frac{dx}{1+x}$ will be the differential of the efficiency, and the efficiency itself will be the integral of this, or, in other words, the Neperian logarithm of the denominator; wherefore the efficiency of the whole stroke will be 1 + Nep. log. $(1+x.)$

Supposing the pressure of the atmosphere to be 15 lbs., 15 + 35 = 50 lbs., and if the steam be cut off at ¼ of the stroke, it will be expanded into four times its original volume; so that at the termination of the stroke its pressure will be 50 ÷ 4 = 12·2 lbs., or 2·8 lbs. less than the atmospheric pressure.

When the steam is cut off at one fourth, it is evident that $x=3$. In such case the efficiency is

$$1+\text{Nep. log. }(1+3),\text{ or }1+\text{Nep. log. }4.$$

The Neperian logarithm of 4 is 1·386294, so that the efficiency of the steam becomes 2·386294; that is, by cutting off the steam at ¼, more than twice the effect is produced with the same consumption of fuel; in other words, one half of the fuel is saved.

CHAPTER IV.

PARALLEL MOTION.

The forms of parallel motion which have been used are so various, that we shall not attempt to enumerate the whole. In what follows, however, we shall treat of those varieties that have been most commonly adopted in land or marine engines; and in doing so, it will be our object both to explain their principles of action, and give practical rules for calculating the lengths of the various parts in every assignable case.

The forms of parallel motion that we shall discuss are four in number; one adapted to land engines, and represented in *fig.* 3; the others used for marine engines, and represented in *figs.* 4, 5, 6. It will be found that all these different arrangements act on the same fundamental principle; and therefore, before going farther, we shall proceed to explain it. Let G C and H F be two levers moving round centres at C and H, and connected together by the rod or link G F. We shall suppose that G C represents the beam of an engine standing in a horizontal position at half stroke. The rod H F represents the radius bar of the parallel motion, and at half stroke it must be horizontal, or parallel to G C. In the present case we shall suppose it to be equal to G C in length. If the beam be made to turn on its centre, so as to cause G to move towards G′, the point E in the middle of the link G F will move upwards nearly in a perpendicular line R′ S′, bisecting the versine D K. This will be evident from the following considerations:—As the point G revolves in the circle G G′, the point F revolves with nearly equal rapidity in the equal circle F F′. Both points, it is evident, will, when the motion commences, approach nearer the line R′S′; and since the circles F F′ and G G′ are of equal radius, and the arcs described are nearly equal, the point F will move towards the line R′ S′ at the same rate at the point G. Both points will cross that line at the same time, and both will respectively reach F′ and G′ simultaneously. F′ L will evidently be equal to G′ K. Now, if the points F and G are always on opposite sides of the line R′ S′, and at the same distance from it, it is clear that the centre of the link E must always be in it; and, accordingly, this would be mathematically true, if G F, by changing its inclination to the perpendicular, did not alter the perpendicular distance between the points F and G. This, however, it does; and as the points G and F ascend the link, G F gets more nearly perpendicular; thus increasing the perpendicular distance between G and F; in consequence of which, at the point where F crosses the perpendicular R′ S′, it has not described quite so large an arc as the point G; or, when F is crossing R′ S′, the point G is still at a small distance from it. This renders the motion of the point E not perfectly coincident with the perpendicular line; but the shortening of the perpendicular distance between G and F, by the vibration of the link G F, when the length of the link is considerable, and the stroke of the beam not greater, in proportion to its length, than usually obtains in steam engines, is so exceedingly small as to be unworthy of the slightest consideration in practice. At either end of the stroke the link G F will have the same inclination as at half stroke, and the point E will therefore be exactly in the perpendicular line R′ S′, at both these points. Its motion will be represented by the curved line R′ O S′, *fig* 7, cutting the perpendicular at R′, O, and S′, and deviating from it by an almost imperceptible quantity at X and W. From the fact, however, of a deviation being caused by the vibration of the link G F, we may infer the propriety of making that vibration as small as possible: and one very obvious precaution to be taken on this ground is, so to place the levers H F and G C at half stroke that the line R′ S′ shall bisect both their versines F L and D K. By this means the link G F vibrates equally on both sides of the perpendicular, and, consequently, never deviates from it so much as if it were to vibrate in one direction during the motion of G to G′. It is not always convenient to have the radius bar H F of the same length as the beam G C: it is sometimes longer, and sometimes shorter. In *fig.* 2 it is represented one half the length of G C. In this case, H F being shorter in proportion to the arc F″ F F′, which it describes, the versine F L is of course greater than in the former case. The lever should still be so placed, however, that the line R′ S′ bisects its versine L F. Owing to the inequality of the versines L F and G K, the middle point of the length G F can no longer move in the line R′ S′; but there is a point E, nearer the end of the link G, that does move nearly in this line. This point is so situated, that G E : E F : : F H : G C. For, within the limits usually assigned to the arcs described by engine-beams,[*] the versines are nearly in the inverse ratio of the radii; that is to say, vers. L F : vers. D K : : G C : H F. Now the vibrations of the points F and G on each side of the line R′ S′ are equal to half the versed sines of the arcs described by these points respectively; that is, to F *f* and G *g*. Hence, F *f* : G *g* : : G C : H F, and by similar triangles F *f* : G *g* : : F E : G E; hence, F E : G E : : G C : H F.

As this proportion holds true at any part of the stroke, it proves that the point E, which divides the link in this proportion, moves in the perpendicular line R S′. When, therefore, the lengths of the levers are given, it is easy to find the point E; but in practice it generally happens (as will be shown subsequently) that the point E is fixed: and we have to find H F. This will be done from this proportion,

$$\text{F E} : \text{E G} :: \text{G C} : \text{H F} = \frac{\text{G C} \cdot \text{E G}}{\text{F E}} \; \ldots\ldots \text{(A).}$$

This proportion is founded on the assumption that the versed sines of the beam and radius bar are inversely as the radii. This, though nearly true, is not exactly so. The versed sines of the smaller radii increase in a greater proportion than the inverse ratio of the radii. The consequence of this is, that the point E in the link G F will be moved too much toward H, and will deviate from the perpendicular in that direction at each end of the stroke. In small engines, and when H F is nearly equal to G C, this deviation will be so small as scarcely to be worthy of notice; but in large engines, and when there is a considerable difference between the lengths of the radius rod and beam, it will be of some consequence. From what has already been said, it will be observed that the deviation is all on one side of the perpendicular; so that the curve described by the point E will be of the shape shown in *fig.* 8. By making a small addition to the length of the radius bar, we can make the deviation take place equally on each side of the perpendicular. We can add so much to its length as to make the point E move towards H too slowly at half stroke; or, in other words, deviate towards C till the beam has got about quarter stroke from the horizontal position, when the point E will cross the perpendicular, and deviate to an equal amount towards H. The curve described by E will then be of the shape shown in *fig.* 9, where the deviations at *m*, *n*, *o*, *p*, are all equal, and only half the deviation at *r* and *s* in the last figure.[†] To facilitate the making of this correction in the length of the radius bar, we give the following table of the amounts to be added to its length for the various proportions that may obtain between it and the beam C G. It is to be observed too, that when the radius bar H F is longer than the beam G C, these amounts are to be *subtracted* from its length.

TABLE (A.)

This column gives $\frac{\text{FH}}{\text{CG}}$ when C G is the greater, and $\frac{\text{CG}}{\text{FH}}$ when F H is the greater.	Correction to be added to or subtracted from the calculated length of the radius bar, in decimal parts of its calculated length.
1·0	0
·9	·0034
·8	·0075
·7	·0163
·6	·0270
·5	·0452
·4	·0817

---

[*] The beam of an engine is usually made at least three times the length of the stroke: so that the sine of the angle which it makes with the horizontal line at the extreme of its stroke, is equal to ⅓ of the radius. The angle whose sine is ⅓ of the radius, is 19° 28′.

[†] Let G C $= r$ G′ G″ $= s$, and arc G″ G G′ $= \phi$; then G K $=$ vers. ϕ;

$$\text{but by Euclid (III. 35), G K (2 G C} - \text{G K)} = (\tfrac{1}{2}\,\text{G}'\,\text{G}'')^2$$

$$\therefore \text{vers.}\,\phi\,(2\,r - \text{vers.}\,\phi = \tfrac{1}{4}\,s^2 \quad \therefore 2\,r\ \text{vers.}\,\phi = \tfrac{1}{4}\,s^2 + \text{vers.}\,^2\phi$$

$$\therefore r = \frac{\tfrac{1}{4}\,s^2 + \text{vers.}^2\phi}{2\ \text{vers.}\phi} = \frac{\tfrac{1}{8}\,s^2 + \tfrac{1}{2}\,\text{vers.}^2\phi}{\text{vers.}\phi}\,;\ \text{or,}\ r = \frac{\tfrac{1}{8}\,s^2}{\text{vers.}\phi} + \tfrac{1}{2}\,\text{vers.}\,\phi$$

$\tfrac{1}{8}\,s^2$ being a constant quantity, this equation shows that the radii are inversely as the versed

TABLE OF NOMINAL HORSES POWER OF STEAM ENGINES.

Length of Stroke in Feet.

Diam. of Cylinder in Inches.	1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4¼	4½	4¾	5	5¼	5½	5¾	6	6¼	6½	6¾	7	7¼	7½	7¾	8	8¼	8½	8¾	9	9¼	9½	9¾	Diam. of Cylinder in Inches.
1	·021	·023	·024	·026	·027	·028	·029	·030	·031	·032	·032	·033	·034	·034	·035	·036	·036	·037	·038	·038	·039	·039	·040	·040	·041	·041	·042	·042	·043	·043	·043	·044	·044	·045	·045	·045	1
1½	·048	·052	·055	·058	·060	·063	·065	·067	·069	·071	·073	·074	·076	·078	·079	·080	·082	·083	·084	·086	·087	·088	·089	·090	·091	·093	,094	·095	·096	·097	·098	·099	·099	·100	·101	·102	1½
2	·085	·092	·097	·103	·107	111	·116	·119	·123	·126	·129	·132	·135	·138	·141	·143	·146	·148	·150	·152	·155	·157	·159	·160	·163	·165	·167	·168	·170	·172	·174	·175	·177	·179	·180	·182	2
2½	133	·143	·152	·160	·168	·176	·180	·186	·192	·197	·202	·207	·211	·215	·220	·224	·227	·231	·235	·238	·242	·245	·248	·251	·254	·257	·260	·263	·266	·269	·271	·274	·277	·279	·282	·284	2½
3	·191	·206	·219	·231	·241	·251	·260	·268	·276	·284	·291	·297	·304	·310	·316	·322	·327	·333	·338	·343	·348	·353	·357	·362	·366	·371	·375	·379	·383	·387	·391	·395	·398	·402	·406	·409	3
3½	·261	·281	·298	·314	·328	·341	·354	·365	·376	·386	·396	·405	·414	·422	·430	·438	·446	·453	·460	·467	·474	·480	·486	[illegible]	·498	·504	·510	·516	·521	·527	·532	·537	·542	·547	·552	·557	3½
4	·340	·367	·390	·410	·429	·446	·462	·477	·491	·504	·517	·529	·540	·551	·562	·572	·582	·592	600	·610	·619	·627	·635	·643	·651	·659	·666	·674	·681	·688	·695	·701	·708	·715	·721	·727	4
4½	·431	·464	·493	·519	·543	·565	·585	·604	·621	·638	·654	·669	·684	·698	·711	·724	·737	·749	·760	·772	·783	·794	·804	·814	·824	·834	·843	·853	·862	·871	·879	·888	·896	·904	·912	·920	4½
5	·532	·573	·609	·641	·670	·697	·722	·745	·767	·788	·808	·826	·844	·862	·878	·894	·910	·924	·939	·953	·966	·980	·993	1·00	1·02	1·03	1·04	1·05	1 06	1·07	1·08	1·09	1·11	1·12	1·13	1·14	5
5½	644	·693	·737	·776	·811	·843	874	·902	·928	·953	·977	1·00	1·04	1·04	1·06	1·10	1·10	1·12	1·14	1·15	1·17	1·19	1·20	1·22	1·23	1·25	1·26	1·27	1·29	1·30	1·31	1·33	1·34	1·35	1·36	1·37	5½
6	·766	·825	·877	·923	·965	1·00	1·04	1·07	1·10	1·13	1 16	1·19	1.22	1·24	1·26	1·29	1·31	1·33	1·35	1·37	1·39	1·41	1·43	1·45	1·47	1·48	1·50	1·52	1·53	1·55	1·56	1·58	1·59	1·61	1·62	1·64	6
6½	·899	·968	1·03	1·08	1·13	1·18	1·22	1·26	1·30	1 33	1·36	1·40	1·41	1·46	1·48	1·49	1·54	1·56	1·59	1·61	1·63	1·66	1·68	1·70	1·72	1·74	1·76	1·78	1·80	1·82	1·83	1·85	1·87	1·89	1·90	1·92	6½
7	1 04	1·12	1·19	1·25	1·31	1·37	1·41	1·46	1·50	1·54	1·58	1·62	1·65	1·69	1·72	1·75	1·78	1·81	1·84	1·87	1·89	1·92	1·95	1·97	1·99	2·02	2·04	2·06	2·09	2·11	2·13	2·15	2·17	5·19	2·21	2·23	7
7½	1·20	1·29	1·37	1·44	1·51	1·57	1·62	1·68	1·73	1·77	1·82	1·86	1·90	1·94	1·98	2·01	2·05	2·08	2·11	2·14	2·17	2·20	2·23	2·26	2·29	2·32	2·34	2·37	2·39	2·42	2·44	2·47	2·49	2·51	2·53	2·56	7½
8	1·36	1·47	1·56	1·64	1·72	1·78	1·85	1·91	1·96	2·02	2·07	2·12	2·16	2·21	2·25	2·29	2·33	2·37	2·40	2·44	2·47	2·51	2·54	2·57	2·60	2·63	2·67	2·69	2·72	2·75	2·78	2·81	2·83	2·86	2·88	2·91	8
8½	1·54	1·66	1·76	1·85	1.94	2·01	2·09	2·15	2·21	2·28	2·33	2·39	2·44	2·49	2·54	2·58	2·63	2·67	2·71	2·75	2·79	2·83	2·87	2·91	2·94	2·97	3·01	3·04	3·07	3·11	3·14	3·17	3·20	3·23	3·26	3·28	8½
9	1·72	1·86	1·97	2·08	2·17	2·26	2·34	2·41	2·49	2·55	2·62	2·68	2·74	2·79	2·84	2·90	2·95	2·99	3·04	3·09	3·13	3·17	3·22	3·26	3·30	3·34	3·37	3·41	3·45	3·48	3·52	3·55	3·59	3·62	3·65	3·68	9
9½	1·92	2·07	2·20	2·31	2·42	2 52	2·60	2·69	2·79	2·84	2·92	2·98	3·05	3·11	3·17	3·23	3·28	3·34	3·39	3·44	3·49	3·54	3·58	3·63	3·67	3·72	3·76	3·80	3·84	3·88	3·92	3·96	3·99	4·03	4·07	4·10	9½
10	2 13	2·29	2·44	2·56	2·68	2·79	2·89	2·98	3·07	3·15	3·23	3·31	3·38	3·45	3·51	3·58	3·64	3·70	3 76	3·81	3·87	3·92	3·97	4·02	4·07	4·12	4·16	4·21	4·26	4·30	4·34	4·38	4·43	4·47	4·51	4·55	10
10½	2·35	2·53	2·68	2·83	2·96	3·07	3·18	3·29	3·38	3·47	3 56	3·64	3·72	3·80	3·87	3·94	4·01	4·08	4·14	4·20	4·26	4·32	4·38	4·43	4·49	4·54	4·59	4·64	4·69	4·74	4·79	4·83	4 88	4·92	4·97	5·01	10½
11	2·57	2·77	2·95	3·10	3·21	3 37	3·49	3·61	3·77	3·81	3·91	4·00	4·15	4·17	4·25	4·30	4·40	4·47	4·54	4·61	4·68	4·74	4·80	4·86	4·92	4·98	5·04	5·09	5·15	5·20	5·25	5·31	5·35	5·40	5·45	5·50	11
11½	2 81	3·03	3 22	3·39	3 54	3·69	3·82	3·94	4·05	4·17	4·26	4·37	4·60	4·56	4·64	4·87	4·87	4·89	4·97	5·04	5·11	5·18	5·25	5·32	5·38	5·45	5·51	5·57	5·63	5·69	5·74	5·80	5·85	5·91	5·96	6·01	11½
12	3·06	3 30	3·51	3·69	3 86	4·01	4·16	4·29	4·42	4·54	4·65	4·76	4·86	4·96	5·06	5·15	5·24	5·32	5·41	5·49	5·57	5·64	5·72	5·79	5·86	5·93	5·99	6·06	6·13	6·19	6·25	6·31	6·37	6·43	6·49	6·54	12
12½	3·32	3·58	3·80	4·01	4·19	4·36	4·51	4·66	4·79	4·92	5·05	5·16	5·28	5·38	5·49	5·59	5·68	5·78	5·86	5·96	6·04	6·12	6·20	6·28	6·36	6·43	6·51	6·58	6·65	6·72	6·78	6·85	6·92	6·98	7·04	7·10	12½
13	3·60	3·87	4·12	4·33	4.53	4·71	4·88	5,04	5·19	5.33	5·46	5·59	5·64	5·82	5·94	5·97	6·15	6·25	6·35	6·44	6·53	6·62	6·71	6·80	6·88	6·96	7·04	7·12	7·19	7·27	7·34	7·41	7·48	7·55	7·62	7·68	13
13½	3·88	4·18	4·44	4·67	4·88	5·08	5·26	5·43	5 59	5 74	5·89	6·02	6·16	6·28	6·40	6·52	6·63	6·74	6·84	6·95	7·05	7·14	7·24	7·33	7·42	7·50	7·59	7·67	7·74	7·84	7·91	7·99	8·07	8·14	8·21	8·28	13½
14	4·17	4·49	4·77	5·03	5·25	5·46	5 66	5·84	6·01	6·18	6·33	6·48	6·62	6·75	6·88	7·01	7·13	7·25	7·36	7·47	7·58	7·68	7·78	7·88	7·98	8·07	8·16	8·25	8·34	8·43	8·51	8·59	8·67	8·75	8·83	8·91	14
14½	4·47	4·82	5·12	5·39	5·64	5·86	6·07	6 27	6·45	6·63	6·79	6·95	7·10	7.26	7·38	7·52	7·65	7·77	7·90	8·01	8·13	8·23	8·34	8·44	8·54	8·65	8·75	8·84	8·94	9·03	9·12	9·21	9·29	9·38	9·46	9·55	14½
15	4·77	5·16	5·48	5·77	6 03	6·27	6·50	6·71	6·90	7·09	7·27	7·44	7·60	7·75	7·90	8·05	8·19	8·32	8·45	8·58	8·70	8·82	8·93	9·05	9·16	9·26	9·37	9·47	9·57	9·67	9·77	9·86	9·96	10·05	10·14	10·23	15
15½	4 95	5·51	5·85	6·16	6·44	6·70	6·94	7·16	7·37	7·57	7·76	7·94	8·11	8·28	8·44	8·59	8·74	8·88	9.02	9·16	9·28	9·41	9·55	9·66	9·78	9·89	10·02	10·13	10·22	10·34	10·44	10·54	10·64	10·74	10·83	10·93	15½
16	5·45	5·87	6·23	6·56	6·86	7·14	7·39	7·63	7·86	8·07	8·27	8·46	8·65	8·82	8·99	9·16	9·31	9·47	9·61	9·76	9·90	10·03	10·16	10·29	10·42	10·54	10·66	10·78	10·89	11·01	11·12	11·22	11·33	11·43	11·54	11·64	16
16½	5·79	6 24	6·63	6 98	7·30	7·59	7·86	8·12	8·35	8·58	8·79	9·00	9·25	9·38	9.56	9·80	9·91	10·07	10·23	10·38	10·53	10·67	10·80	10·95	11·08	11·21	11·34	11·46	11·58	11·70	11·82	11·94	12·05	12·16	12·27	12·38	16½
17	6·15	6 62	7·04	7·41	7·75	8·06	8·35	8·61	8·86	9·11	9·34	9·55	9·76	9·96	10·15	10·34	10·52	10·69	10·85	11·02	11·17	11·33	11·47	11·62	11·76	11·90	12·04	12·17	12·30	12·42	12·55	12·67	12·79	12·90	13·02	13·14	17
17½	6·52	7·02	7·46	7·85	8·21	8·54	8·84	9·14	9·40	9·65	9 89	10·12	10·34	10·55	10·76	10·95	11·14	11·32	11·50	11·67	11·84	12·00	12·16	12·31	12·46	12·61	12·75	12·89	13·03	13·16	13·30	13·43	13·55	13·67	13·80	13·92	17½
18	6·89	7·43	7·89	8·31	8 68	9·03	9·36	9·66	9·94	10·21	10·47	10·71	10·94	11·17	11·38	11·59	11·79	11·98	12·17	12·35	12·53	12·70	12·86	13·03	13·19	13·34	13·49	13·64	13·79	13·93	14·07	14·21	14·34	14·47	14·6	14·73	18
18½	7·28	7·84	8·33	8·77	9·17	9·54	9·88	10 21	10·55	10·79	11·06	11·32	11·56	11·80	12·03	12·25	12·46	12·66	12·87	13·05	13·22	13·40	13·58	13·75	13·96	14·08	14·24	14·39	14·56	14·71	14·85	14·99	15·14	15·27	15·41	15·54	18½
19	7·68	8·27	8.79	9·26	9·68	10·07	10·42	10 76	11·17	11·38	11·66	11·93	12·19	12·44	12·68	12·91	13·13	13·35	13·56	13·76	13·96	14·15	14·33	14·51	14·69	14·86	15·03	15·20	15·36	15·52	15·67	15·83	15·98	16·12	16·27	16·41	19
19½	8·09	8 71	9·26	9·75	10·19	10·60	10.98	11·34	11·67	11·98	12·28	12·57	12·69	13·10	13·26	13·44	13·84	14·06	14·28	14·49	14·70	14·90	15·10	15·29	15·48	15·66	15·84	16·01	16·18	16·35	16·51	16·67	16·83	16·98	17·14	17·28	19½
20	8·51	9·17	9 71	10·26	10·72	11·15	11·55	11·92	12·27	12·60	12·92	13·22	13·51	13·79	14·05	14·31	14·55	14·79	15·02	15·25	15·46	15·68	15·88	16·08	16·28	16·47	16·66	16·84	17·02	17·20	17·37	17·54	17.70	17·86	18·02	18·18	20
20½	8·94	9 63	10·24	10·78	11·26	11·72	12·13	12·53	12·89	13·24	13·65	13·89	14·35	14·48	14·86	15·19	15·29	15·54	15·78	16·02	16·25	16·47	16·69	16·90	17·11	17·30	17·50	17·69	17·88	18·07	18·25	18·42	18·60	18·78	18·94	19·10	20½
21	9·38	10·11	10·89	11·31	11·82	12·29	12.73	13·14	13·53	13·90	14·25	14·58	14·89	15·20	15·49	15·77	16·04	16·31	16·56	16·81	17·05	17·28	17·51	17·73	17·94	18·16	18·36	18·57	18·77	18·96	19·15	19·34	19·52	19·69	19·87	20·05	21
21½	9·83	10·59	11·26	11·85	12·29	12·89	13·35	13·78	14·19	14·57	14·86	15·28	15·46	15·93	16·14	16·37	16·82	17·09	17·36	17·62	17·87	18·12	18·35	18·59	18·81	19·03	19·25	19·46	19·67	19·87	20·07	20·26	20·46	20·61	20·83	21·01	21½
22	10·30	11·09	11·79	12·41	12·97	13·49	13·98	14·43	14·85	15·25	15·63	16·00	16·62	17·08	17·30	17·59	17·65	17·90	18·18	18·45	18·71	18·96	19·22	19·46	19·70	19·93	20·16	20·38	20·60	20·81	21·01	21·22	21·42	21·62	21·81	22·00	22
22½	10·77	11·60	12·33	12·95	13·57	14·12	14·62	15·10	15·54	15·96	16·35	16·73	17·10	17 45	17·78	18·11	18·42	18·72	19·01	19·30	19·57	19·84	20·10	20·36	20·60	20·85	21·08	21·32	21·54	21·76	21·98	22·20	22·40	22·61	22·81	23·01	22½
23	11·25	12·12	12·88	13·56	14·18	14·75	15·28	15·77	16·22	16·67	17·05	17·49	18·40	18·23	18·58	19·49	19·25	19·56	19·87	20·17	20·45	20·73	21·01	21·27	21·53	21·79	22·04	22·27	22·51	22·74	22·97	23·19	23·41	23·63	23·83	24·05	23
23½	11·75	12·66	13·45	14·16	14·80	15·40	15·95	16·46	16·92	17·40	17·76	18·25	18·73	19·03	19·40	19·90	20·10	20·42	20·74	21·05	21·35	21·64	21·93	22·21	22·48	22·74	23·00	23·25	23·50	23·74	23·98	24·21	24·44	24·67	24·88	25·10	23½
24	12·26	13·20	14·03	14·77	15·44	16·06	16·63	17·17	17·67	18·15	18·61	19·04	19·45	19·85	20·23	20·60	20·95	21·30	21·63	21·95	22·27	22·57	22·87	23·16	23·44	23·72	23·99	24·25	24·51	24·76	25·01	25·25	25·49	25·73	25·96	26·18	24
24½	12·77	13·76	14·62	15·39	16·09	16·73	17·33	17·89	18·44	18·92	19·47	19·84	20·20	20·69	21·09	21·32	21·84	22·20	22·54	22·87	23·21	23·52	23·83	24·13	24·43	24·72	25·00	25·27	25·54	25·81	26·06	26·32	26·56	26·81	27·05	27·28	24½
25	13·30	14·32	15·22	16·02	16·75	17·42	18·05	18·63	19·18	19·70	20·19	20·66	21·11	21·54	21·95	22·35	22·74	23·11	23·47	23·82	24·16	24·49	24·82	25·13	25·44	25·74	26·03	26·31	26·59	26·87	27·14	27·40	27·66	27·92	28·16	28·41	25
25½	13·84	14·90	15·84	16·67	17·43	18·13	18·78	19·38	19·83	20·49	21·01	21·49	21·96	22·41	22·84	23·26	23·66	24·04	24·42	24·78	25·14	25·49	25·82	26·15	26·46	26·77	27·08	27·38	27·67	27·96	28·24	28·51	28·78	29·04	29 30	29·56	25½
26	14·39	15·49	16·46	17·33	18·12	18·85	19·52	20·15	20·75	21·31	21·84	22·35	22·56	23·30	23·75	23·89	24·60	25·00	25·39	25·76	26·14	26·49	26·84	27·18	27·51	27·83	28·15	28·46	28·78	29·06	29·35	29·64	29·92	30·19	30·46	30·72	26
26½	14·94	16·09	17·10	18·01	18·82	19·58	20·28	20·93	21·60	22·14	22·68	23·21	23·18	24·20	24·67	24·55	25·56	25·97	26·37	26·76	27·16	27·53	27·89	28·24	28·59	28·92	29·25	29·58	29·88	30·20	30·50	30·80	31·10	31·37	31·65	31·93	26½
27	15·51	16·71	17·75	18·69	19·54	20·32	21·05	21·73	22·37	22·97	23·55	24·10	24·62	25·12	25·61	26·07	26·52	26·96	27·38	27·79	28·18	28·57	28·95	29·31	29·67	30·02	30·36	30·70	31·02	31·34	31·66	31·96	32·26	32·56	32·85	33·14	27
27½	16·09	17·33	18·42	19·39	20·27	21·08	21·84	22·55	23·07	23·82	24·43	25·00	25·58	26·06	26·56	27·02	27·50	27·97	28·40	28·83	29·24	29·64	30·03	30·41	30·78	31·14	31·50	31·84	32·18	32·51	32·83	33·16	33·47	33·78	34·07	34·38	27½
28	16·68	17·97	19·09	20·10	21·02	21·86	22·64	23·37	24·06	24·71	25·33	25·91	26·48	27·02	27·54	28·04	28·52	28·99	29·44	29·89	30·31	30·72	31·13	31·52	31·90	32·28	32·65	33·01	33·36	33 70	34·04	34·37	34·69	35·01	35·33	35·64	28
28½	17·28	18 62	19·78	20·83	21·77	22·65	23·45	24·21	25·12	25·6	26·24	26·85	27·43	27·99	28·53	29·05	29·55	30·04	30·51	30·96	31·40	31·83	32·25	32·66	33·06	33·45	33·82	34·20	34·56	34·92	35·27	35·61	35·95	36·28	36·60	36·92	28½
29	17·89	19·27	20·48	21·56	22·54	23·45	24·28	25·07	25·81	26·50	27·17	27·80	28·41	28·98	29·54	30·08	30·60	31·10	31·59	32·06	32·48	32·92	33·35	33·78	34·18	34·58	34·98	35·37	35·79	36·11	36·48	36·83	37·17	37·50	37·85	38·18	29
29½	18·52	19·95	21·19	22·31	23·33	24·21	25·12	25·94	26·50	27·43	28·11	28·77	29·40	29·99	30·57	31·12	31·66	32·18	32·68	33·17	33·64	34·09	34·54	34·98	35·40	35·82	36·23	36·63	37 03	37·40	37·78	38·14	38·50	38·85	39·20	39·54	29½
30	19·15	20 63	21·92	23·08	24·13	25·09	25·99	26·85	27·62	28·36	29·07	29·75	30·40	31·02	31·61	32.19	32·74	33·28	33·80	34·31	34·80	35·27	35·74	36·19	36·63	37·06	37·48	37·89	38·30	38·69	39·08	39·46	39·83	40·20	40·56	40·91	30
30½	19·79	21·32	22·66	23·85	24·94	25·94	26·86	27·73	28·54	29·32	30·05	30·75	31·41	32·06	32·68	33·27	33·85	34·40	34·94	35·46	35·97	36·48	36·97	37·43	37·90	38·33	38·77	39·20	39·59	40·02	40·42	40·82	41·20	41·59	41·95	42·31	30½
31	20·45	22·03	23·41	24·64	25·76	26·79	27·75	28·65	29·49	30·29	31·04	31·77	32·45	33·12	33·76	34·37	34·96	35·54	36·09	36·63	37·15	37·70	38·20	38·68	39·17	39·60	40·07	40·51	40·89	41·36	41·77	42·18	42·58	42·98	43·35	43·71	31
31½	21·11	22·74	24·17	25·44	26·60	27·61	28·65	29·58	30·45	31·27	32·05	32·8	33·51	34·20	34·85	35·49	36·10	36·69	37·26	37·82	38·36	38·89	39·40	39·90	40·38	40·86	41·31	41·78	42·22	42·65	43·09	43·51	43·91	44·31	44·71	45·11	31½
32	21·79	23·47	24·96	26·25	27·51	28·55	29·57	30·52	31·42	32·27	33·08	33·85	34·59	35·29	35·97	36·62	37·26	37·86	38·46	39·03	39·59	40·13	40·66	41·17	41·68	42·17	42·64	43·11	43·57	44·02	44·46	44·9	45·32	45·73	46·14	46·54	32
32½	22·47	24·21	25·72	27·08	28·31	29·45	30·50	31·49	32·41	33·29	34·12	34·92	35·68	36·40	37·10	37·78	38·43	39·06	39·67	40·26	40·84	41·40	41·94	42·47	42·99	43·49	43·99	44·47	44·96	45·41	45·87	46·31	46·74	47·17	47·60	48·01	32½
33	23·17	24·95	26·52	27·92	29·19	30·38	31·46	32·46	33·40	34·32	35·18	36·00	36·80	37·53	38·25	38·97	39·62	40·27	40·90	41·51	42·10	42·68	43·24	43·79	44·32	44·85	45·36	45·85	46·34	46·82	47·28	47·75	48·19	48·64	49·07	49·51	33
33½	23·88	25·72	27·33	28·77	30·08	31·32	32·42	33·45	34·41	35·37	36·25	37·10	37·92	38·67	39·42	40·15	40·83	41·50	42·15	42·78	43·39	44·00	44·57	45·13	45·68	46·22	46·75	47·26	47·76	48·26	48·74	49·21	49·67	50·12	50·57	51·02	33½
34	24·60	26·49	28·16	29·64	30·99	32·27	33·39	34·46	35·44	36·43	37·34	38·21	39·04	39·84	40·60	41·34	42·06	42·74	43·41	44·06	44·69	45·32	45·90	46·48	47·05	47·60	48·14	48·67	49·19	49·70	50·20	50·68	51·16	51·60	52·08	52·54	34
34½	25·32	27·28	28·99	30·52	31 91	33·25	34·38	35·48	36·49	37·51	38·36	39·34	40·40	41·02	41·81	42·84	43·31	44·01	44·70	45·37	46·02	46·65	47·26	47·86	48·44	49·03	49·58	50·12	50·65	51·18	51·67	52·19	52·68	53·17	53·63	54·11	34½
35	26 06	28·08	29·84	31·41	32·84	34·15	35·37	36·52	37·59	38·61	39·57	40·49	41·37	42·22	43·03	43·81	44·57	45·30	46·00	46·69	47·36	48·01	48·64	49·26	49·85	50·44	51·01	51·58	52·13	52·66	53·19	53·71	54·21	54·70	55·20	55·69	35
35½	26·81	28·88	30·69	32·31	33·78	35·14	36·39	37·57	38·71	39·72	40·80	41·66	42·36	43·43	44·27	44·80	45·85	46·60	47·33	48·03	48·73	49·40	50·05	50·68	51·30	51·90	52·49	53·07	53·63	54·19	54·73	55·26	55·78	56·29	56·80	57·30	35½
36	27·572	29·70	31·56	33·23	34·74	36·13	37·42	38·63	39·77	40·84	41·87	42·84	43·77	44·66	45·52	46·35	47·15	47·92	48·67	49·40	50·11	50·79	51·46	52·11	52·75	53·37	53·97	54·57	55·15	55·72	56·28	56·82	57·36	57·88	58·40	58·91	36
36½	28·35	30·53	32·45	34·16	35·71	37·14	38·47	39·71	40·80	41·99	42·94	44·04	45·20	45·92	46·80	47·93	48·47	49·27	50·03	50·78	51·50	52·20	52·89	53·55	54·29	54·85	55·47	56·08	56·69	57·27	57·84	58·40	58·95	59·49	60·02	60·55	36½
37	29·13	31·38	33·34	35·10	36·70	38·17	39 53	40·82	41·97	43·15	44·18	45·26	46·35	47·19	48·10	49·11	49·81	50·64	51·42	52·19	52·89	53·62	54·32	55·00	55·84	56·33	56.97	57·60	58·26	58·82	59·40	59·98	60·55	61·10	61·64	62·18	37
37½	29·92	32·23	34·25	36·06	37·70	39·21	40·61	41·92	43·15	44·32	45·43	46·48	47·49	48·46	49·40	50·29	51·16	52·00	52·81	53·60	54·37	55·11	55·84	56·54	57·24	57·91	58·57	59·21	59·84	60·46	61·06	61·65	62·23	62·82	63·36	63·92	37½
38	30·72	33·10	35·17	37·02	38·71	40·26	41·69	43·05	44·66	45·51	46·64	47·73	48·77	49·77	50·72	51·64	52·54	53·40	54·23	55·04	55·83	56·59	57·34	58·06	58·78	59·46	60·13	60·80	61·45	62·08	62·70	63·31	63·91	64·50	65·06	65·63	38
38½	31·54	33·97	36·10	38·00	39·73	41·32	42·80	44·19	45·67	46·72	47·88	49·00	49·77	51·09	51·88	52·70	53·94	54·82	55·68	56·51	57·32	58·10	58·86	59·61	60·34	61·04	61·73	62·42	63·07	63·73	64·37	65·00	65·61	66·21	66·80	67·38	38½
39	32·36	34·86	37·04	39 00	40·77	42·41	43·92	45·34	46·69	47·94	49·13	50·28	51·76	52·42	53·03	53·76	55·35	56·24	57·12	57·97	58·81	59·61	60·39	61·16	61·91	62·63	63·34	64·04	64·72	65·39	66·05	66·69	67·31	67·93	68·54	69·13	39
39½	33·20	35·76	38·00	40·00	41·82	43·5	45·05	46·52	47·89	49·18	50·41	51·58	52·90	53·78	54·62	55·49	56·78	57·70	58·61	59·48	60·33	61·16	61·96	62·75	63·51	64·26	64·99	65·70	66·39	67·09	67·76	68·42	69·06	69·69	70·32	70·93	39½
40	34·04	36·67	38·97	41·02	42·89	45·61	46·20	47·69	49·10	50·42	51·69	52·89	54·04	55·14	56·20	57·22	58·21	59·17	60·09	60·99	61·859	62·71	63·53	64·34	65·12	65·89	66·63	67·37	68·08	68·79	69·47	70·15	70·81	71·46	72·10	72·73	40
40½	34·90	37 59	39·95	42·06	43·97	46·73	47·36	48·89	50·33	51·69	52·99	54·22	55·40	56·53	57·62	58·67	59·68	60·65	61·60	62·52	63·42	64·29	65·13	65·96	66·78	67·55	68·31	69·07	69·80	70·52	71·23	71·92	72·60	73·29	73·93	74·57	40½
41	35 77	38·53	40·94	43·10	45 06	47·87	48·54	50·11	51.56	52·97	54·59	55·56	57·38	57·94	59·45	60·76	61·15	62·16	63·14	64·08	64·99	65·88	66·74	67·59	68·45	69·22	70·00	70·78	71·53	72·26	72·99	73·70	74·39	75·12	75·76	76·42	41
41½	36·64	39·47	41·95	44·17	46·17	48·02	49·73	51·34	52·84	54·28	55·78	56·93	58·48	59·36	60·71	61·92	62·66	63·70	64·69	65·66	66·60	67·58	68·39	69·19	70·08	70.98	71·72	72·62	73·29	74·04	74·79	75·52	76·22	76·92	78·02	78·30	41½
42	37·53	40·43	42·96	45·23	47·29	49·18	50·94	52·58	54·13	55·60	56·98	58·31	59·58	60·79	61·96	63·09	64·18	65·23	66·25	67·24	68·21	69·13	70·04	70·93	71·78	72·63	73·45	74·27	75·06	75·83	76·60	77·34	78·06	78·77	79·49	80·19	42
42½	38·43	41·40	43·99	46·31	48·42	50·36	52·16	53·84	55·44	56·94	58·21	59·71	60·71	62·25	63·26	64·29	65·72	66·80	67·85	68·86	69·83	70·79	71·72	72·63	73·51	74·37	75·22	76·05	76·86	77·65	78·43	79·19	79·94	80·66	81·40	82·10	42½
43	39·34	42·38	45·03	47·41	49·57	51·55	53·39	55·11	56·75	58·28	59·44	61·12	61·84	63·72	64·55	65·49	67·28	68·37	69·44	70·48	71·49	72·46	73·42	74·35	75·25	76·14	77,00	77·85	78·68	79·49	80·28	81·07	81·82	82·58	83·32	84·06	43
43½	40·26	43·37	46·09	48·52	50·72	52·76	54·64	56·40	58·06	59·64	61·13	62·55	63·91	65·21	66·47	67·68	68·84	69·97	71·07	72·13	73·17	74·16	75·13	76·09	76·99	77·91	78·79	79·67	80·52	81·34	82·17	82·97	83·73	84·58	85·27	86·04	43½
44	41·19	44·37	47·15	49·64	51·90	53·98	55·91	57·71	59·38	61·02	62·54	64·00	66·46	68·32	68·00	70·39	70·44	71·60	72·71	73·80	74·85	75·88	76·87	77·84	78·79	79·73	80·63	81·52	82·38	83·23	84·06	84·88	85·68	86·47	87·23	88·01	44
44½	42·13	45·39	48·23	50·77	53·08	55·21	57·18	59·03	60·76	62·41	63·97	65·46	67·42	69·05	69·56	71·40	72·05	73·23	74·38	75·49	76·57	77·62	78·64	79·63	80·61	81·56	82·48	83·39	84·27	85·14	85·99	86·83	87·65	88·46	89·24	90·03	44½
45	43·08	46·41	49·32	51·92	54·28	56·46	58·48	60·36	62·14	63·82	65·42	66·94	68·39	69·79	71·13	72·43	73·67	74·88	76·05	77·19	78·30	79·36	80·41	81·43	82·43	83·39	84·33	85·27	86·17	87·06	87·93	88·79	89·63	90·45	91·26	92·05	45
45½	41·05	47·45	50·42	53·08	55·50	57·72	59·78	61·71	63·51	65·25	66·80	68·43	69·88	71·35	72·73	74·02	75·32	76·56	77·76	78·92	80·05	81·14	82·21	83·25	84·27	85·27	86·23	87·18	88·10	89·02	89·89	90·78	91·63	92·49	93·30	94·12	45½
46	45·02	48·50	51·54	54·25	56·72	58·99	61·10	63·07	64·88	66·69	68·19	69·94	71·43	72·92	74·33	75·65	76·99	78·25	79·47	80·66	81·81	82·93	84·02	85·08	86·12	87·16	88·14	89·10	90·04	90·98	91·86	92·78	93·64	94·53	95·34	96·20	46
46½	46·01	49·56	52.66	55·44	57·96	60·28	62·44	63·46	66·35	68·14	69·86	71·48	73·02	74·52	75·95	77·34	78·66	79·96	81·21	82·42	83·59	84·75	85·86	86·94	88·04	89·05	90·07	91·06	92·01	92·97	93·89	94·81	95·72	96·61	97·45	98·27	46½
47	47·00	50·63	53·80	56·64	59·22	61·59	63·79	65·83	67·68	69·62	71·03	73·02	74·92	76·12	77·60	79·58	80·38	81·68	82·97	84·22	85·40	86·57	87·71	88·82	89·90	90·98	92·01	93·01	94·00	94·97	95·91	96·85	97·76	98·67	99·54	100·4	47
47½	48·00	51·71	54·95	57·85	60·48	62·90	65·15	67·25	69·19	71·1	72·72	74·58	76·36	77·76	79·26	80·99	82·09	83·43	84·74	86·01	87·23	88·42	89·59	90·72	91·84	92·91	93·96	95·01	96·01	96·99	97·97	98·93	99·86	100·8	101·7	102·6	47½
48	49·02	52·81	56·11	59·07	61·76	64·24	66·53	68·68	70·70	72·62	74·42	76·16	77·82	79·40	80·94	82·40	83·83	85·20	86·53	87·82	89·08	90·30	91·49	92·65	93·78	94·88	95·95	97·02	98·04	99·06	100·0	101·0	102·0	103·0	103·8	104·7	48
48½	50·05	53·91	57·29	60·31	63·06	65·58	67·93	70·12	72·24	74·14	76·15	77·76	79·29	81·07	82·63	83·84	85·58	86·98	88·34	89·66	90·95	92·20	93·41	94·59	95·70	96·88	97·97	99·06	100·1	101·1	102·1	103·1	104·1	105·1	106·0	106·9	48½
49	51·08	55·03	58·48	61·56	64·36	66·94	69·33	71·58	73·78	75·68	77·88	79·37	80·78	82·76	84·35	85·30	87·36	88·78	90·16	91·50	92·82	94·10	95·34	96·54	97·73	98·88	100·0	101·1	102·2	103·2	104·3	105·3	106·3	107·2	108·2	109·1	49
49½	52·13	56·16	59·68	62·82	65·68	68·31	70·75	72·04	75·15	77·22	79·15	80·99	84·13	84·44	86·07	88·18	89·15	90·61	92·02	93·40	94·74	96·03	97·20	98·53	99·72	100·9	102·1	103·2	104·3	105·3	106·4	107·4	108·4	109·4	110·4	111·4	49½

Length of Stroke in Feet.

50	53·19	57·26	60·88	64·10	67·02	69·69	72·19	74·56	76·71	78·79	80·76	82·64	84·44	86·16	87·82	89·41	90·96	92·45	93·89	95·20	96·66	97·98	99·27	100·8	101·7	102·9	104·1	105·3	106·4	107·5	108·5	109·6	110·6	111·7	112·6	113·6	50
50½	54·15	58·43	62·06	65·30	68·37	71·10	73·65	76·02	78·09	80·28	82·39	84·30	86·14	87·90	89·50	91·22	92·79	94·31	95·78	97·21	98·6	99·94	101·2	102·5	103·7	105·4	106·2	107·4	108·6	109·6	110·7	111·8	112·8	113·9	114·9	115·9	50½
51	55·3	59·61	63·35	66·60	69·72	72·52	75·11	77·52	79·34	81·97	84·02	85·94	87·88	89·64	91·36	93·03	94·62	96·16	97·68	99·14	100·6	101·9	103·2	104·6	105·8	107·1	108·3	109·5	110·7	111·8	112·9	114·0	115·1	116·1	117·2	118·2	51
51½	56·42	60·78	64·60	68·01	71·10	73·95	76·59	79·06	81·17	83·60	85·67	87·64	89·05	91·41	93·17	94·30	96·51	98·08	99·61	101·1	102·5	103·9	105·3	106·6	107·9	109·2	110·4	111·6	112·9	114·0	115·6	116·2	117·3	118·4	119·5	120·5	51½
52	57·53	61·96	65·86	69·33	72·44	75·39	78·08	80·60	83·00	85·23	87·35	89·34	90·25	93·19	94·98	95·57	98·40	99·99	101·55	103·1	104·5	106·0	107·4	108·7	110·0	111·3	112·6	113·8	115·1	116·2	117·4	118·5	119·6	120·8	121·8	122·9	52
52½	58·65	63·17	67·14	70·67	73·86	76·85	79·60	82·19	84·70	86·89	89·04	91·12	92·56	95·00	96·83	98·56	100·3	101·9	103·5	105·0	106·5	108·5	109·4	110·8	112·2	113·5	114·8	116·0	117·3	118·5	119·7	120·8	121·9	123·1	124·2	125·3	52½
53	59·76	64·38	68·42	72·02	75·30	78·32	81·12	83·72	86·40	88·55	90·74	92·86	94·88	96·81	98·68	98·19	102·24	103·8	105·5	107·0	108·6	110·4	111·5	112·9	114·2	115·7	117·0	118·3	119·5	120·7	121·9	123·1	124·3	125·4	126·6	127·7	53
53½	60·90	65·60	69·72	73·39	76·73	79·81	82·66	85·32	87·94	90·21	92·47	94·62	96·64	98·65	100·5	102·3	104·1	105·8	108·0	109·1	110·6	112·3	113·6	113·8	116·4	117·8	119·2	120·5	121·7	122·9	124·1	125·4	126·7	127·8	129·0	130·1	53½
54	62·04	66·83	71·02	74·76	78·17	81·30	84·20	86·92	89·48	91·88	94·20	96·39	98·49	100·50	102·4	104·3	106·1	107·8	109·5	111·1	112·7	114·3	115·8	117·2	118·7	120·0	121·4	122·8	124·1	125·4	126·6	127·8	129·0	130·2	131·4	132·5	54
54½	63·20	68·08	72·35	76·16	79·63	82·82	85·77	88·55	90·89	93·58	95·96	98·19	100·4	102·3	104·3	106·3	108·0	109·8	111·5	113·2	114·8	116·4	118·0	119·4	120·9	122·2	123·7	125·1	126·4	127·7	128·9	130·2	131·4	132·6	133·8	135·0	54½
55	64·36	69·33	73·68	77·56	81·09	84·34	87·35	90·19	92·30	95·28	97·73	100·00	102·3	104·2	106·2	108·4	110·0	111·9	113·61	115·3	116·9	118·5	120·1	121·6	123·1	124·6	126·0	127·4	128·7	130·0	131·3	132·6	133·8	135·1	136·3	137·5	55
55½	65·54	70·60	75·03	78·98	82·58	85·88	88·95	91·83	94·26	97·06	99·51	101·8	104·1	106·1	108·1	110·3	112·0	114·4	115·7	117·4	119·0	120·6	122·3	123·9	125·7	126·8	128·2	129·6	131·1	132·4	133·7	135·0	136·3	137·5	138·7	139·9	55½
56	66·72	71·88	76·34	80·41	84·07	87·43	90·55	93·48	96·23	98·84	101·30	103·6	105·9	108·0	110·1	112·2	114·1	116·0	117·8	119·5	121·2	122·9	124·5	126·1	127·6	129·1	130·6	132·0	133·4	134·8	136·2	137·5	138·8	140·0	141·3	142·6	56
56½	67·92	73·17	77·75	81·85	85·58	89·00	92·17	95·17	98·36	100·6	103·1	105·5	107·8	110	112·1	114·2	116·9	118·0	119·8	121·6	123·4	125·1	126·7	128·3	129·9	131·5	133·0	134·4	135·8	137·2	138·6	139·9	141·3	142·5	143·8	145·1	56½
57	69·13	74·46	79·13	83·30	87·10	90·58	93·80	96·86	100·49	102·4	104·9	107·4	109·7	112·0	114·1	116·2	118·2	120·1	122·0	123·8	125·6	127·3	129·0	130·6	132·2	133·8	135·3	136·8	138·2	139·7	141·0	142·4	143·8	145·1	146·4	147·6	57
57½	70·35	75·78	80·53	84·77	88·64	92·18	95·47	98·56	101·8	104·2	106·7	109·3	111·6	113·9	116·1	118·2	120·3	122·2	124·2	126·0	127·8	129·6	131·3	132·9	134·6	136·2	137·7	139·2	140·7	142·2	143·5	144 9	146·3	147·7	148·9	150·3	57½
58	71·58	77·10	81·93	86·25	90·18	93·79	97·14	100·27	103·2	106·0	108·6	111·2	113·6	115·9	118·2	120·3	122·4	124·4	126·3	128·2	129·9	131·7	133·4	135·1	136·7	138·3	139·9	141·5	143·1	144·4	145·9	147·3	148·7	150·0	151·4	152·7	58
58½	72·82	78·44	83·35	87·75	91·75	95·31	98·81	102·0	104·6	107·8	110·5	113·1	115·6	117·9	120·2	122·4	124·5	126·5	128·5	130·4	132·3	134·1	135·9	137·7	139·3	141·0	142·6	144·1	145·7	147·2	148·6	150·1	151·5	152·9	154·3	155·6	58½
59	74·06	79·78	84·78	89·25	93·32	96·83	100·48	103·7	106·0	109·7	112·4	115·0	117·6	119·9	122·2	124·5	126·6	128·7	130·7	132·7	134·6	136·4	138·2	139·9	141·6	143·3	144·9	146·5	148·1	149·6	151·1	152·6	154·0	155·4	156·8	158·2	59
59½	75·33	81·14	86·23	90·77	94·91	98·60	102·2	105·5	108·2	111·5	114·3	117	119·6	122·0	124·3	126·6	128·3	130·9	132·9	134·9	136·9	138·7	140·5	142·2	144·0	145·7	147·4	149·0	150·6	152·2	153·7	155·2	156·6	158·1	159·5	160·9	59½
60	76·60	82·51	87·68	92·30	96·50	100·37	103·9	107·3	110·4	113·4	116·3	119·0	121·6	124·1	126·4	128·7	131·0	133·1	135·2	137·2	139·2	141·1	142·9	144·7	146·5	148·2	149·9	151·6	153·2	154·8	156·3	157·8	159·3	160·8	162·2	163·6	60
60½	77·88	83·89	89·15	93·85	98·12	102·0	105·6	109·1	113·3	115·3	118·2	121·0	123·6	126·1	128·5	130·9	133·2	135·8	137·4	139·4	141·4	143·3	145·4	147·2	149·0	150·7	152·5	154·2	155·7	157·4	158·9	160·5	162·0	163·6	165·0	166·4	60½
61	79·17	85·28	90·63	95·40	99·75	103·7	107·4	110·9	114·2	117·2	120·2	123·0	125·6	128·2	130·7	133·1	135·4	137·6	139·7	141·8	143·9	145·9	147·9	149·7	151·6	153·3	155·1	156·8	158·3	160·1	161·7	163·3	164·8	166·4	167·8	169·2	61
61½	80·46	86·69	92·13	96·99	101·39	105·46	109·2	112·8	116·1	119·2	122·9	125·1	129·2	130·4	133·8	136·8	137·7	139·9	141·9	144.0	146·2	148·3	150·3	152·1	154·0	155·7	157·5	159·3	161·0	162·7	164·3	165·8	167·4	169·1	170·5	171·9	61½
62	81·79	88·10	93·62	98·56	103·04	107·17	111·00	114·59	117·96	121·14	124·18	127·07	129·81	132·48	135·03	137·49	139·86	142·14	144·37	146·52	148·6	150·8	152·8	154·7	156·7	158·4	160·3	162·0	163·6	165·4	167·1	168·7	170·3	171·9	173·4	174·8	62
62½	83·12	89·32	95·14	100·16	104·37	108·8	112·8	116·4	119·8	123·06	126·2	129·1	131 9	134 5	137·2	139·7	142·1	144·4	146·9	148·9	151·0	153·1	155·2	157·1	159·1	160·9	162·7	164·5	166·6	168·0	169·7	171·3	172·9	174·5	176·1	177·6	62½
63	84·45	90·97	96·67	101·76	106·40	110·66	114·62	118·31	121·80	125·08	128·22	131·20	134·05	136·78	139·42	141·96	144·40	146·77	149·06	151·29	153·4	155·5	157·6	159·6	161·5	163·4	165·2	167·1	168·9	170·6	172·3	174·0	175·6	177·2	178·8	180·4	63
63½	85·8	92·41	98·20	103·39	108·2	112·5	116·4	120·2	123·7	127·0	130·2	133·2	136·1	138·9	141·5	144·0	146·7	149·0	151·44	153·7	155·9	158·0	160·1	162·1	164·1	166·0	167·9	169·7	171·6	173·3	175·0	176·8	178·4	180·0	181·7	183·3	63½
64	87.15	93·88	99 84	105·02	110·0	114·2	118·3	122·1	125·7	129·1	132·3	135·4	138·3	141·2	143·9	146·5	149·0	151·4	153·82	156·13	158·4	160·5	162·6	164·7	166·7	168·7	170·6	172·4	174·3	176·1	177·8	179·6	181·3	182·9	184·6	186·2	64
64½	88·52	95·25	101·37	106 6	111·6	116·0	120·1	123·9	127·5	131·1	134·3	137·5	140·4	143·3	146·1	148·7	151·3	153·8	156·24	158·5	160·8	162·0	165·2	167·3	169·3	171·3	173·2	175·1	177·0	178·8	180·6	182·4	184·1	185·8	187·5	189·1	64½
65	89·90	96·84	102·90	108·3	113·2	117·8	122·0	125·9	129·6	133·1	136·5	139·6	142·7	145·6	148·40	151·1	153·7	156·2	158·66	161·04	163·3	165·6	167·8	169·9	172·0	174·0	175·9	177·9	179·8	181·6	183·4	185·2	187·0	188·7	190·4	192·0	65
65½	91·29	98·31	104·5	110·0	115 0	119·6	123·8	127·8	131·6	135·1	138·6	141·8	145·0	147·9	150·7	153·4	156·0	158·6	161·1	163·5	165·8	168·1	170·4	172·5	174·6	176·7	178·6	180·6	182·6	184·4	186·2	188·1	189·9	191·6	193·3	195·0	65½
66	92·68	99·79	106·1	111·7	116·8	121·5	125·8	129·8	133·6	137·3	140·7	144·0	147·3	150·2	153·0	155·7	158·5	161·1	163·60	166·0	168·4	170·7	173·0	175·1	177·3	179·4	181·4	183·4	185·4	187·2	189·1	191·0	192·8	194·6	196·2	198·0	66
66½	94·09	101·3	107·7	113·3	118·5	123·3	127·7	131·8	135·6	139·3	142·8	146·1	149·4	152·3	155·3	158·1	160·9	163·5	166·1	168·5	171·0	173·3	175·6	177·8	180·0	182·1	184·2	186·2	188·2	190·1	192·0	193·9	195·7	197·5	199·2	201·0	66½
67	95.51	102·9	109·3	115·1	120·3	125·2	129·7	133·8	137·6	141·4	145·0	148·3	151·5	154·7	157·7	160·5	163·3	166·0	168·6	171·1	173·6	176·0	178·2	180·5	182·7	184·9	187·0	189·0	191·0	193·0	195·0	196·8	198·7	200·5	202·3	204·1	67
67½	96·95	104·4	110·9	116 8	122·1	127·1	131·6	135 8	139·7	143·5	147·2	150·5	153·8	157·0	162·4	162 9	167·7	168·5	171·1	173·6	176·2	178·6	180·9	183·2	185·4	187·6	189·8	191·8	193·9	195·9	197·9	199·7	201·6	203·4	205·3	207·1	67½
68	98·4	106·0	112·6	118·6	123·9	129·1	133·6	137·8	141 8	145·7	149·4	152·8	156·2	159·4	162·4	165·4	168·2	171·0	173·6	176·2	178·8	181·3	183·6	185·9	188·2	190·4	192·6	194·7	196·8	198·8	200·8	202.7	204·6	206·4	208·3	210·2	68
68½	99 9	107·5	114·2	120·3	125·7	131·1	135·6	139·8	143·9	147·8	151·4	155·1	158·5	161·7	164·8	167·8	170·7	173·5	176·2	178·8	181·4	183·9	186·3	188·6	191·0	193·2	195·4	197·6	199·7	201·7	203·7	205·7	207·6	209·5	211·4	213·2	68½
69	101·3	109·1	115·9	122·0	127·6	133·0	137 5	141·9	146·0	150·0	153·4	157·4	160 6	164·0	167·2	171·3	173·2	176·0	178·8	181·5	184·0	186·6	189·0	191·4	193·8	196·1	198·3	200·5	202·6	204·7	206·7	208·7	210·7	212·7	214·5	216·4	69
69½	102·8	110·7	117·6	123·8	129·4	134 8	139·3	143·7	148·2	152·2	157·8	159·7	163·0	166·4	169·6	173·2	175·7	178·6	181·4	184·1	186·7	189·3	191·8	194·2	196·6	198·9	201·1	203·4	205·5	207·6	209·7	211·7	213·7	215·7	217·6	219·6	69½
70	104·26	112 3	119·3	125·6	131·3	136·6	141·5	146·0	150·4	154·4	158·3	162·0	165·5	168·8	172·1	175·2	178·2	181·2	184·0	186·8	189·4	192·0	194·6	197·0	199·4	201·7	204·0	206·3	208·5	210·6	212·8	214·8	216·8	218·8	220·8	222·8	70
70½	105·8	113·9	121·0	127·4	133·2	138·5	143·5	147·1	152·6	156·6	160·5	164·3	167·7	171·2	174·5	177·2	180·8	183·8	186·6	189·4	192·1	195·8	197·4	199·8	202·3	204·6	207·0	209·3	211·5	213·6	215·8	217·9	219·9	222·0	224·0	226·0	70½
71	107·2	115·5	122·8	129·2	135·1	140·5	145·6	150·3	154·8	158·8	163·2	166·6	169·4	173·7	177·0	180·2	183·4	186·4	189·3	192·1	194·9	197·6	200·2	202·7	205·2	207·6	210·0	212·3	214·5	216·7	218·9	221·0	223·1	225·2	227·2	229·2	71
71½	108·7	117·1	124·5	131·0	137·0	142·7	147·6	152·4	158·9	161·1	165·3	169·0	172·2	176·1	179·5	182·8	186·0	189·0	192·0	194·8	197·6	200·4	203·0	205·5	208·1	210·5	212·9	215·2	217·5	219·7	222·0	224·1	226·2	228·3	230·4	232·4	71½
72	110·3	118·8	126·2	132·9	139·0	144·5	149·7	154·5	159·1	163·4	167·4	171·4	175·1	178·6	182·1	185·4	188·6	191·7	194·7	197·6	200·4	203·2	205·8	208·4	211·0	213·5	215·9	218·2	220·6	222·8	225·1	227·3	229·4	231·5	233·6	235·6	72
72½	111·8	120·4	128·0	134·7	140·9	146·5	151·8	156·1	161·1	165·6	169·6	173·7	177·4	181·1	184·6	188·5	191·2	194·4	197·4	200·3	203·2	206·0	208·7	211·3	214·1	216·4	218·9	221·2	223·7	225·9	228·2	230·4	232·6	234·7	236·8	238·9	72½
73	113·4	122·1	129·8	136·6	142·8	148·6	153·9	158·8	163·2	167·9	171·8	176·1	179·8	183·6	187·2	191·7	193·9	197·1	200·1	203·1	206·0	208·8	211·6	214·2	217·2	219·4	221·9	224·3	226·8	229·1	231·4	233·6	235·8	238·0	240·1	242·2	73
73½	114·9	123·8	131·6	138·5	144·8	150·6	156·0	161·0	165·5	170·2	174·2	178·5	182·6	186·2	189·8	194·0	196·5	199·8	202·9	205·9	208·8	211·6	214·4	217·1	220·3	222·3	224·9	227·3	229·9	232·2	234·5	236·7	239·0	241·2	243·3	245·4	73½
74	116·5	125·5	133·4	140·4	146·8	152·6	158·1	163·3	167·9	172·6	176·7	181·0	185·4	188·8	192·4	196·4	199·2	202·6	205·7	208·8	211·6	214·5	217·3	220·0	223·4	225·3	227·9	230·4	233·0	235·3	237·6	239·9	242·2	244·4	246·6	248·7	74
74½	118·1	127·3	135·2	142·4	148·8	154·7	160·2	166·6	170·6	174·9	179·3	183·4	187·4	191·4	195·0	198·9	201·9	205·2	208·4	213·5	214·5	217·5	220·4	223·3	226·0	228·4	231·1	233·6	236·2	238·6	240·9	243·3	245·6	248·0	250·0	252·3	74½
75	119·7	128·9	137·0	144·2	150·8	156·8	162·4	167·7	172·6	177·3	181·7	185·9	190·0	193·8	197·6	201·2	204·6	208·0	211·2	214·4	217·4	220·5	223·3	226·2	229·0	231·6	234·2	236·8	239·4	241·8	244·2	246·6	248·9	251·3	253·4	255·7	75
75½	121·3	130·5	138·8	146·0	152·8	158·9	164·6	169·9	174·6	179·6	184·1	188·4	192·5	196·4	200·2	203·9	207·3	210·8	214·0	217·3	220·3	223·5	226·3	229·2	232·0	234·8	237·3	240·0	242·6	245·0	247·5	249·9	252·2	254·6	256·8	259·1	75½
76	122·9	132·4	140·7	148·1	154·8	161·0	166·8	172·2	178·6	182·0	186·6	190·9	195·0	199·0	202·9	206·6	210·1	213·6	216·9	220·2	223·3	226·4	229·4	232·2	235·1	237·8	240·5	243·2	245·8	248·3	250·8	253·2	255·6	258·0	260·2	262·5	76
76½	124·5	134·1	142·5	149·0	156·8	163·1	169·0	174·5	180·6	184·4	189·0	193·4	197·6	201·7	205·2	208·8	212·9	216·4	219·7	223·1	226·2	229·4	232·4	235·3	238·2	241·0	243·7	246·4	249·0	251·6	254·1	256·5	259·0	261·4	263·6	265·9	76½
77	126·1	135·9	144·4	152·0	158·9	165·3	171·2	176·8	182·7	186·9	191·5	196·0	200·2	204·4	207·5	210·8	215·8	219·3	222·7	226·0	229·3	232·4	235·4	238·4	241·4	244·2	246·9	249·7	252·3	254·9	257·5	260·0	262·4	264·8	267·2	269·5	77
77½	127·7	137·6	146·3	153·5	161·0	167·4	173·4	179·1	184·7	188·4	194·0	198·5	202·8	207·1	209·8	212·9	218·6	222·1	225·5	228·9	232·2	235·4	238·5	241·5	244·5	247·3	250·1	252·9	255·6	258·2	260·8	263·3	265·8	268·2	270·7	273·0	77½
78	129·4	139·4	148·2	156·0	163·1	169·6	175·6	181·4	186·7	191·8	196·5	201·1	205·4	209·7	212·1	215·0	221·4	225·0	228·5	231·9	235·2	238·4	241·6	244·6	247·6	250·5	253·4	256·2	258·9	261·6	264·2	266·7	269·2	271·7	274·2	276·5	78
78½	131·1	141·2	150·1	158·0	165·2	171·7	177·9	183·7	189·2	194·2	199·0	203·7	208·0	212·4	215·3	218·5	224·2	227·9	231·4	234·9	238·2	241·5	244·7	247·8	250·8	253·7	256·7	259·5	262·2	265·0	267·6	270·2	272·7	275·2	277·7	280·1	78½
79	132·8	143·0	152·0	160·0	167·3	174·0	180·2	186·1	191·6	196·7	201·6	206·3	210·6	215·1	218·5	222·0	227·1	230·8	234·4	237·9	241·3	244·6	247·8	251·0	254·0	257·0	260·0	262·8	265·6	268·4	271·0	273·7	276·2	278·8	281·3	283·7	79
79½	134·5	145·8	153·9	162·0	169·4	176·2	182·5	188·4	194·0	199·2	204·1	208·9	213·3	217·8	221·6	225·9	229·9	233·7	237·4	240·9	244·3	247·7	250·9	254·1	257·2	260·2	263·3	266·1	268·9	271·8	274·4	277·1	279·7	282·3	284·8	287·3	79½
80	136·2	146·7	155·8	164·1	171·6	178·4	184·8	190·8	196·4	201·7	206·7	211·5	216·1	220·6	224·8	229·9	232·8	236·6	240·4	243·9	247·4	250·8	254·1	257·3	260·5	263·5	266·5	269·5	272·3	275·1	277·9	280·6	283·2	285·8	288·4	290·9	80
80½	137·9	148·5	157·8	166·1	173·7	180·5	187·1	193·2	198·8	204·2	209·3	214·2	218·8	223·3	227·6	232·2	235·7	239·6	243·4	247·0	250·5	254·0	257·3	260·5	263·8	266·8	269·8	272·9	275·7	278·6	281·4	284·0	286·8	289·5	292·0	294·6	80½
81	139·6	150·4	159·8	168·2	175·9	182·6	189·4	195·6	201·3	206·8	211·9	216·9	221·6	226·1	230·5	234·6	238·7	242·6	246·4	250·1	253·7	257·2	260·5	263·8	267·1	270·2	273·2	276·3	279·2	282·1	284·9	287·7	290·4	293·2	295·7	298·3	81
81½	141·3	152·2	161·8	170·3	178·0	184·8	191·8	198·0	203·7	209·3	214·6	219·5	224·2	228·9	234·1	238·8	241·6	245·6	249·4	253·2	256·8	260·3	263·7	267·1	270·4	273·5	276·6	279·7	282·6	285·6	288·4	291·2	294·0	296·8	299·3	302·0	81½
82	143·0	154·1	163·8	172·4	180·2	187·2	194·2	200·4	206·2	211·9	217·3	222·2	226·9	231·7	237·8	241·2	244·6	248·6	252·5	256·3	260·0	263·5	267·0	270·4	273·8	276·9	280·0	283·1	286·1	289·0	292·0	294·8	297·6	300·5	303·0	305·7	82
82½	144·8	156·0	165·8	174·5	182·4	189·6	196·6	202·9	2 8·8	214·5	220·2	224·9	229·5	234·4	240·3	245·3	247·6	251·7	255·6	259·4	263·2	266·7	270·3	273·5	277·1	280·4	283·4	286·8	289·6	292·6	295·6	298·4	301·2	304·5	307·5	309·4	82½
83	146·6	157·9	167·8	176·6	184·6	192·0	198·9	205·4	211·4	217·1	223·1	227·7	233·9	237·4	242·8	247·7	250·6	254·8	258·8	262·6	266·4	270·0	273·6	276·7	280·3	283·9	286·9	290·5	293·1	296·2	299·2	302·1	304·9	308·5	312·1	313·2	83
83½	148·4	159·8	169·8	178·7	186·8	194·3	201·3	207·9	213·9	219·7	225·5	230·4	236·1	240·2	245·3	250·0	253·6	257·9	261·9	265·8	269·6	273·2	276·9	280·2	283·7	287·2	290·3	293·8	296·6	299·8	302·8	305·7	308·5	311·7	315·0	317·0	83½
84	150·1	161·7	171·8	180·9	189·1	196·7	203·8	210·3	216·5	222·4	227·9	233·2	238·3	243·2	247·8	252·3	256·7	260·9	265·0	269·0	272·8	276·5	280·2	283·7	287·1	290·5	293·8	297·1	300·2	303·3	306·4	309·4	312·2	315·0	317·9	320·8	84
84½	151·9	163·6	173·9	183·0	191·4	199·0	206·2	212·8	219·1	225·1	230·3	236·0	240·5	246·1	250·4	254·7	259·8	264·0	268·2	272·2	276·0	279·8	283·5	287·1	290·5	294·0	297·3	300·6	303·8	306·9	310·0	313·1	316·0	318·8	321·7	324·6	84½
85	153·7	165 6	176·0	185·2	193·7	201·4	208·6	215·4	221·8	227·8	232·8	238·8	242·8	249·0	253·0	257·2	262·9	267·2	271·4	275·4	279·3	283·2	286·9	290·5	294·0	297·5	300·9	304·2	307·4	310·6	313·7	316·8	319·8	322·6	325·6	328·4	85
85½	155·5	167·5	178·0	187·4	195·9	203·7	211·1	217·9	224·4	230·4	235·3	241·6	245·1	251·9	255·6	259·5	266·0	270·3	274·6	278·6	282·6	286·5	290·3	293·9	297·3	301·0	304·4	307·8	311·0	314·3	317·4	320·5	323·5	326·4	329·4	332·3	85½
86	157·4	169·5	180·1	189·6	198·2	206·2	213·6	220·4	227·0	233·1	237·8	244·5	247·4	254·8	258·2	261·9	269·1	273·5	277·8	281·9	286·0	289·8	293·7	297·4	301·0	304·6	308·0	311·4	314·7	318·0	321·1	324·3	327·3	330·3	333·3	336·2	86
86½	159·1	171·5	182·1	191·8	200·6	208·6	216·1	223·0	229·6	235·8	241·7	247·3	252·6	257·8	262·7	267·6	272·1	276·7	280·9	285·2	289·4	293·2	297·0	300·9	304·4	308·0	311·4	315·7	318·4	321·5	325·0	328·0	331·0	334·5	337·1	340·2	86½
87	161·0	173·4	184·3	194·0	202·9	211·0	218·6	225·6	232·2	238·5	244·5	250·2	255·6	260·8	265·8	270·7	275·4	279·9	284·2	288·5	292·7	296·6	300·5	304·4	308·0	311·6	315·1	318·7	322·1	325·3	328·7	331·8	334·9	338·3	341·0	344·1	87
87½	162·9	175·4	186·4	196·2	205·2	213·4	221·1	228·2	234·6	241·2	247·3	253·1	258·6	263·8	268·9	273·8	278·5	283·1	287·5	291·8	296·0	300·0	304·0	307·9	311·6	315·2	318·8	322·4	325·8	329·1	332·4	335·6	338·8	342·1	344·9	348·0	87½
88	164·8	177·5	188·6	198·5	207·6	215·9	223·6	230·8	237·5	244·0	250·2	256·0	261·6	266·9	272·0	277·0	281·7	286·4	290·8	295·2	299·4	303·5	307·5	311·4	315·2	318·9	322·5	326·1	329·5	332·9	336·2	339·5	342·7	345·9	348·9	352·0	88
88½	166·7	179·5	190·7	200·8	209·9	218·3	226·1	233·4	240·1	246·8	253·0	258·9	264·6	269·9	275·1	280·1	284·9	289·6	294·1	298·6	302·8	307·0	311·0	314·9	318·8	322·5	325·7	329·8	333·2	336·7	340·1	343·4	346·6	349·8	352.9	356·0	88½
89	168·5	181·5	192·9	203·1	212·3	220·8	228·7	236·1	243·0	249·6	255·9	261·8	267·6	273·0	278·2	283·3	288·2	292·9	297·5	302·0	306·3	310·5	314·6	318·5	322·4	326·2	328·9	333·6	337·0	340·6	344·0	347·3	350·6	353·8	356·9	360·1	89
89½	170·4	183·5	195·1	205·4	214·7	223·3	231·3	238·7	245·8	252·4	258·8	264·7	270·6	276·1	281·3	286·5	291·4	296·2	300·8	305·3	309·7	313·9	318·1	322·1	326·0	329·9	333·1	337·3	340·8	344·4	347·8	351·2	354·6	357·7	360·9	364·1	89½
90	172·3	185·6	197·3	207·7	217·1	225·8	233·9	241·4	248·6	255·3	261·7	267·7	273·6	279·2	284·5	289·7	294·7	299·5	304·2	308·7	313·2	317·4	321·6	325·7	329·7	333·6	337·3	341·1	344·7	348·2	351·7	355·2	358·5	361·8	365·0	368·2	90
90½	174·2	187·7	199·5	210·0	219·5	228·3	236·5	243·1	251·3	258·1	264·4	270·7	276·5	282·3	287·7	292·9	298·0	302·8	307·6	312·2	316·7	321·0	325·2	329·3	333·4	337·3	341·1	344·9	348·5	352·1	355·6	358·1	362·5	365·9	369·1	372·3	90½
91	176·2	189·8	201·7	212·3	222·0	230·8	239·1	246·8	254·0	261 0	267·2	273·7	279·5	285·4	290·9	296·1	301·3	306·2	311·0	315·7	320·2	324·6	328·8	333·0	337·1	341·1	344·9	348·7	352·4	356·1	359·6	363·1	366·5	370·0	373·2	376·5	91
91½	178·1	191·9	203·9	214·6	224·4	233·6	241·6	249·5	256·7	263·8	270·0	276·7	282·6	288·5	294·1	299·3	304·6	309·6	314·4	319·1	323·7	328·1	332·4	336·6	340·8	344·8	348·7	352·5	356·3	360·0	363·5	367·1	370·5	374·0	377·3	380·6	91½
92	180·1	194·0	206·1	217·0	226·9	236·0	244·4	252·3	259·5	266·7	272·8	279·8	285·7	291·7	297·3	302·6	307·9	313·0	317·9	322·6	327·2	331·7	336·1	340·3	344·5	348·6	352·6	356·4	360·2	363·9	367·4	371·1	374·6	378·1	381·4	384·8	92
92½	182·0	196·1	208·3	219·4	229·3	238·5	247·1	255·0	262·4	269·6	276·1	282·8	288·8	294·9	300·5	305·9	311·2	316·4	321·3	326·1	330·8	335·3	339·7	344·0	348·3	352·4	356·4	360·3	364·1	367·9	371·5	375·1	378·7	382·2	385·6	388·9	92½
93	184·0	198·2	210·6	221·8	231·8	241·1	249·8	257·8	265·4	272·6	279·4	285·9	292·0	298·1	303·8	309·3	314·6	319·8	324·8	329·6	334·4	339·0	343·4	347·8	352·2	356·2	360·3	364·2	368·0	371·9	375·6	379·2	382·9	386·4	389·8	393·1	93
93½	186·0	200·3	212·9	224·1	234·3	243·7	252·5	260·5	268·0	275·5	281·7	288·9	295·3	301·3	307·1	312·6	318·0	323·2	328·3	333·2	338·0	342·5	347·1	351·5	355·9	360·0	364·1	368·1	372·0	375·9	379·6	383·3	386·9	390·5	394·0	397·4	93½
94	188·0	202·5	215·2	226·5	236·8	246·3	255·2	263·3	270·7	278·5	284·1	292·0	298·6	304·5	310·4	315·9	321·5	326·7	331·8	336·8	341·6	346·3	350·8	355·3	359·6	363·9	368·0	372·0	376·0	379·9	383·6	387·4	391·0	394·7	398·2	401·7	94
94½	190·0	204·6	217·5	228·9	239·3	248·9	257·9	266·1	273·7	281·4	287·5	295·1	302·0	307·7	313·7	319·9	324·9	330·2	335·4	340·4	345·2	350·0	354·6	359·1	363·5	367·7	371·9	376·0	380·0	383·9	387·7	391·5	395·2	398·9	402·4	405·9	94½
95	192·0	206·8	219·8	231·4	241·9	251·6	260·6	269·0	276·8	284·4	290·9	298·3	305·4	311·0	317·0	324·0	328·4	333·7	339·0	344·0	348·9	353·7	358·4	362·9	367·4	371·6	375·8	380·0	384·0	388·0	391·9	395·7	399·4	403·1	406·7	410·2	95
95½	194·0	209·0	222·1	233·7	244·4	254·2	263·3	271·8	279·8	287·4	294·3	301·4	308·4	314·3	320·3	326·8	331·8	337·2	342·5	347·6	352·6	357·4	362·2	366·7	371·2	375·5	379·8	384·0	388·1	392·1	396·0	399·9	403·6	407·3	411·0	414·5	95½
96	196·1	211·2	224·4	236·3	247·0	256·9	266·1	274·7	282·8	290·4	297·7	304·6	311·2	317·6	323·7	329·6	335·3	340·8	346·1	351·3	356·3	361·2	366·0	370·6	375·1	379·5	383·8	388·1	392·2	396·2	400·2	404·1	407·9	411·6	415·3	418·9	96
96½	198·1	213·4	226·8	238·7	249·6	259·6	268·9	277 6	285·9	293·5	301·1	307·8	314·2	320·9	327·1	332·5	338·8	344·3	349·7	354·9	360·0	365·0	369·8	374·5	378·9	383·5	387·8	392·1	396·3	400·3	404·3	408·2	412·1	415·8	419·6	423·2	96½
97	200·2	215·6	229·2	241·2	252·2	262·3	271·7	280·5	289·0	296·6	304·6	311·0	317·2	324·3	330·5	335·4	342·3	347·9	353·4	358·6	363·8	368·8	373·6	378·4	382·8	387·5	391·9	396 2	400·4	404·4	408·4	412·4	416·4	420·1	424·0	427·6	97
97½	202·3	217·8	231·4	243·6	254·8	265·0	274·5	283·4	292·1	299·7	308·0	314·2	320·3	327·6	333·9	338·7	345·8	351·4	356·9	362·2	367·5	372·6	377·4	382·3	386·6	391·6	395·9	400·2	404·5	408·5	412·5	416·5	420·6	424·3	428·3	431·9	97½
98	204·3	220·1	233·9	246·2	257·4	267·7	277·3	286·3	295·1	302·7	311·5	317·5	323·1	331·0	337·4	341·2	349·4	355·1	360·6	366·0	371·3	376·4	381·4	386·2	390·9	395·5	400·0	404·4	408·7	412·9	417·0	421·0	425·0	429·0	432·8	436·6	98
98½	206·4	222·3	236·3	248·7	260·0	270·4	280·1	289·5	297·8	305·8	314·0	320·7	326·8	334·4	340·8	345·8	353·0	358·7	364·3	369·8	375·1	380·2	385·1	390·2	394·9	399·5	404·1	408·5	412·8	417·1	421·3	425·4	429·4	433·4	437·2	441·1	98½
99	208·5	224·6	238·7	251·3	262·7	273·2	283·0	292·8	300·6	308·9	316·6	324·0	330·5	337·8	344·3	350·4	356·6	362·4	368·1	373·6	379·0	384·1	388·8	394·1	398·9	403·6	408·2	412·7	417·0	421·4	425·6	429·8	433·8	437·8	441·6	445·6	99
99½	210·6	226·9	241·1	253·8	265·3	277·0	285·9	296·0	303·7	312·0	319·8	327·2	334·2	341·2	347·7	355·0	360·2	366·1	371·8	377·4	382·8	387·9	392·9	398·1	402·9	407·7	412·3	416·8	421·2	425·6	429·9	434·1	438·2	442·2	446·1	450·1	99½
100	212·8	229·2	243·5	256·4	268·0	278·8	288·8	298·1	306 8	315·2	323·0	330·5	337·7	344·6	351·2	357·6	363·8	369·8	375·6	381·2	386·6	391·9	397·0	402·1	407·0	411·8	416·5	421·0	425·5	429·9	434·2	438·4	442·6	446·6	450·6	454·6	100

It will be observed that the greater the difference between the lengths of the radius bar and beam, the greater is the amount of the correction to be made. As an example of the use of the table, suppose we have the length of the beam C G = 38 inches, and that the radius bar has been found by proportion (A) to be 15¼ inches; 15¼ ÷ 38 is nearly ·4: we shall therefore get for the corrected length of the radius bar 15¼ + ·0817 × 38 = 16·76 inches. The application of this correction to the length of the radius bar, will in all cases diminish the amount of the deviation from the perpendicular by one half; but it should be borne in mind that the parallel motion will work most accurately when the radius bar and beam C G are of the same length; and they should therefore be kept as nearly equal as circumstances will permit.

The simple arrangement of two levers connected by a link, which we have now described, is sometimes used as a parallel motion; but additional rods and connecting links are generally superadded, which render the application of the principle more convenient in practice. *Fig.* 3. represents the parallel motion in most general use for land engines; and *fig.* 4. a similar one adapted for marine side-lever engines. The general arrangement in both of these is the same, except that the marine engine motion has the reverse side uppermost. We have marked all the corresponding parts in the two figures with the same letters, so that what we have to say of the one will refer equally to the other. In land engines, the radius bar H F is generally either equal to or longer than G C, the part of the beam which works it; while, in the marine engine motion, the radius bar is usually shorter than the part of the beam that gives it motion. This difference is shown in the figures. Referring now to *figs.* 3 and 4., we shall explain the method of applying the principles we have already described to the calculation of the proportions of the several parts. D C is the beam or side lever moving on the centre C; H F, the radius bar moving on the centre H, and connected with the beam by the rod F G. D P is another rod equal in length to G F; and P F is a rod equal in length to D G. The three rods, therefore, D P, P F, and F G, with the part D G of the beam, form a parallelogram; and the piston-rod is attached to the point P, which, at half stroke, is in the perpendicular line R S, bisecting the versed sine D K. When the engine is put in motion, this point P will move nearly in the perpendicular line R S. For, suppose the beam to be moved upwards into the position D′ C, the point will then be in the position P′, and the positions of the various other points are denoted by corresponding accented letters. Join C P and C P′, and also E E′, and we will have, by similar triangles, P E : E C :: D G : G C :: D′ G′ : G′ C, and P′ E′ : E′ C :: D′ G . G′ C; hence, P E : E C :: P′ E′ : E′ C.

Therefore (Euclid vi. 2.) P P′ is parallel to E E′. Let the length of F H be made such, that $\mathrm{HF} = \frac{\mathrm{GC} + \mathrm{EG}}{\mathrm{FE}}$, and by equation A, the point E will move in a perpendicular line; but P P′ having been proved to be parallel to the line E E′ in which E moves, the point P must also move in a perpendicular line. Again, referring to equation (A), we have

$$\mathrm{EF} : \mathrm{EG} :: \mathrm{GC} : \mathrm{HF}, \text{ but by similar triangles}$$
$$\mathrm{EF} : \mathrm{EG} :: \mathrm{FP} : \mathrm{GC} :: \mathrm{DG} : \mathrm{GC}$$
$$\text{hence, } \mathrm{DG} : \mathrm{GC} :: \mathrm{GC} : \mathrm{HF} = \frac{\mathrm{GC}^2}{\mathrm{DG}} \quad . \; . \; . \; . \quad (B).$$

This equation will give us the length of the radius bar H F, when the length of C G is determined. In land engines the air pump is generally wrought from the point E, and the centre G is fixed so as to be most convenient for that purpose. Formula (B), is therefore very useful for determining the proper length of the radius rod in such cases. In marine engines, however, the position of the centre H of the radius bar is generally fixed from other considerations, and it becomes necessary to find at what point the centre G should be placed, so as to make P move in a perpendicular line.

To enable us to determine this,

Let H F + G C = a = the horizontal distance of the centre * H, from the main centre, plus half the versed sine of the arc, described by the extremity D of the beam

$$\mathrm{DG} + \mathrm{GC}, \text{ or } \mathrm{DC} = b$$
$$\text{then, } \mathrm{GC} = a - \mathrm{HF} \;\therefore \mathrm{DG} = b + \mathrm{HF} - a$$
$$\text{hence, (B) . . } \mathrm{HF} = \frac{(a - \mathrm{HF})^2}{b + \mathrm{HF} - a} = \frac{a^2 + \mathrm{HF}^2 - 2a . \mathrm{HF}}{b^2 + \mathrm{HF} - a}$$
$$\therefore \mathrm{HF}^2 + \mathrm{HF}(b - a) = a^2 + \mathrm{HF}^2 - 2a . \mathrm{HF}$$
$$\left.\begin{array}{l} \therefore \mathrm{HF} = \dfrac{a^2}{b + a} \\ \text{or, } \mathrm{HF} = \dfrac{(\mathrm{GF} + \mathrm{GC})^2}{\mathrm{GF} + \mathrm{GC} + \mathrm{DC}} \end{array}\right\} \quad . \; . \; . \; . \; . \quad (C)$$

This equation will give us the length of H F; and to get G C, we have

$$\mathrm{GC} = a - \mathrm{HF} \quad . \; . \; . \; . \; . \; . \quad (C')$$

These three equations therefore, (B), (C), and (C′) enable us to calculate the proportions of this form of parallel motion in all circumstances.

In *figs.* 5 and 6, two other forms of parallel motion in common use for marine engines are represented. In *fig.* 5. the radius bar, instead of being connected as formerly to the crosshead, is connected by the rod F Q to the side rod by a pin at Q. F Q is made equal, and parallel to G D; and F G equal, and parallel to Q D. In *fig.* 6. the centre H of the radius bar is placed much farther from the main centre. It may be on either side of the piston rod, as is found most convenient. In this motion, too, the end F of the radius bar is connected by a pin to the upright rod G V. The rod G V is made equal and parallel to the side rod D P, and the rod P V is made equal and parallel to D G.

To enable us to investigate the method of calculating the lengths of the parts in these motions, join as before C P, and C P′, and from the point T where C P cuts F Q in *fig.* 5. or H F in *fig.* 6. draw T T′ parallel to D P. These lines being drawn in both figures, the following investigation will apply to either:—

Let D C = b = C G + G T′ + T′ D
P Q = e
F H = r
P D = s
G C + F H = a = the horizontal distance of H from the main centre + (½ versine arc D′ D D″ × $\frac{s-c}{s}$ *

It may be proved in the same way, as for *fig.* 4. that the point P moves in a line parallel to that described by the point E, so that the inquiry resolves itself as before into an investigation of the relative lengths of C G, and F H, that will cause the point E to move in a perpendicular line. Let us suppose, first, that the height of the centre H of the radius bar, and consequently the height also of the pin Q, is fixed, and that the point G, or the length of C G, is also determined. It is required to find from these data the proper length of H F. By equation (A) we have
C G : F H :: F E : E G, but by similar triangles F T : G C :: F E : E G;

$$\text{hence, } \mathrm{TF} : \mathrm{GC} :: \mathrm{CG} : \mathrm{FH} = \frac{\mathrm{GC}^2}{\mathrm{TF}} = \frac{\mathrm{GC}^2}{\mathrm{T'G}}$$
$$\text{but, } \mathrm{T'G} = \mathrm{CT'} - \mathrm{CG}, \text{ and by similar triangles}$$
$$\mathrm{DP} : \mathrm{QD} :: \mathrm{DC} : \mathrm{CT'} = \frac{\mathrm{DC} \cdot \mathrm{QD}}{\mathrm{DP}} = \frac{b(s-c)}{s}$$
$$\text{hence, } \mathrm{T'G} = \frac{b(s-c)}{s} - \mathrm{CG} = \frac{b(s-c) - s \cdot \mathrm{CG}}{s}$$
$$\text{and, } \mathrm{FH} = \frac{\mathrm{GC}^2 \cdot s}{b(s-c) - s \cdot \mathrm{CG}} \quad . \; . \; . \; . \quad (D)$$

Again, if the length of G C is not given, but the positions of the centre H, and the pin Q are fixed, let it be required to find the lengths of H F and G C. We shall have the same as above

$$\mathrm{FH} = \frac{\mathrm{GC}^2}{\mathrm{T'G}} = \frac{(a-r)^2}{\mathrm{T'C} - a + r}$$
$$\text{or } r = \frac{(a-r)^2}{\mathrm{T'C} - a + r}$$
$$\therefore r(\mathrm{T'C} - a + r) = a^2 + r^2 - 2a^2$$
$$\therefore r(\mathrm{T'C} + a) = a^2$$
$$\therefore r = \frac{a^2}{\mathrm{T'C} + a}$$

But it was shown above that $\mathrm{T'C} = \frac{b(s-c)}{s}$ hence

$$r = \frac{a^2 s}{as + b(s-c)} \quad . \; . \; . \; . \; . \quad (E).$$

This equation will give the length of H F, and to get G C we have

$$\mathrm{GC} = a - r \quad . \; . \; . \; . \quad (E')$$

Again, suppose that the lengths of the levers H F and C G, and consequently the horizontal distance of the centre H from the main centre are given. Let it be required to find the height of the centre H and point Q

From equation E we get

$$as \cdot r + b(s-c) \cdot r = a^2 s$$
$$\therefore asr + brs - brc = a^2 s$$
$$\therefore brc = asr + brs - a^2 s$$

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sines only when ½ vers φ is indefinitely small in comparison with r; and that, by any increase of the versed sine (½ s^2 being always constant), the radius diminishes in a less ratio than the versed sine increases, and *vice versa*. Of course the converse of this is true also; that, if the radius be diminished, the versed sine increases in a greater ratio, and *vice versa*.

When the beam is just leaving the horizontal position, the versed sine is indefinitely small in comparison of the radius; and therefore, at this point, the versed sine of the beam and radius bar will be inversely as the radii; and H F, as determined by equation (A), will be correct for this part of the stroke. At either end of the stroke, however, it ought to be equal to $\frac{\text{versed sine D K G C}}{\text{versed sine F L}}$. Now, as it cannot have both these values, the nearest approach to accuracy we can make is, to make its length intermediate between these two. The corrections in the Table are computed on this principle.

* If a perpendicular H M be let fall from H on D C, M C will be the horizontal distance of the centre H, from the main centre; and since F G is parallel to P D, it is evident that F H + G C = a = M C + D N.

* ½ versine of arc D′ D D″ × $\frac{s-c}{s}$ is the excess of the distance of the point D, from the line R S, over the distance of the point Q from the same line. Comparing this with the last note, the correctness of the value given above to a will be evident.

$$\therefore c = \frac{asr+brs-a^2s}{br} = \frac{(ar+br-a^2)s}{br}$$

$$\text{or, } c = \frac{(a+b)r-a^2}{br} ds \quad . \; . \; . \; . \; . \quad \text{(F.)}$$

It may be observed that, if c in formulas (D) and (E), is taken equal to nothing they become the same as formulas (B) and (C).

Having now investigated formulas for calculating the proportions of all the parallel motions we proposed to examine, we shall conclude by collecting these formulas together for the greater convenience of reference, and subjoin practical rules deduced from them for the use of those who prefer rules to algebraic formulas.

The sum of the lengths of the radius bar, and the part of the beam (C G) which works it. - - - $= a =$ Horizontal distance of the centre of the radius bar (H) from the main centre, plus half the versed sine of the arc described by extremity of the beam (D)

Radius of side lever or engine beam, (D C) - - - - - $=b$

Length of radius bar - (H F) $=r$

Length of side rod - (P D) $=s$

Part of side rod above the centre of radius bar - - (P Q) $=c$

Part of connecting link intercepted between the beam and the point E (G E) - - - - - $=p$

The remaining part of the connecting link - - - (F E) $=p'$

Length of that part of the beam that works the radius bar (G C) $=r'$

$$\left.\begin{aligned} r &= \frac{r' \cdot p}{p'} \\ p' &= \frac{r'(p+p')}{(r+r')} \end{aligned}\right\} \cdot \; \cdot \; \textit{Figs. } 1 \text{ and } 2 \; . \; . \; . \; (\text{A})$$

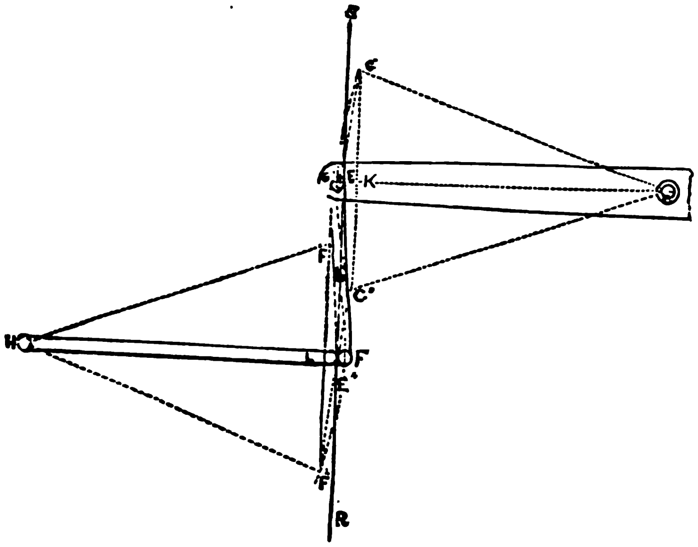


Fig. 1.

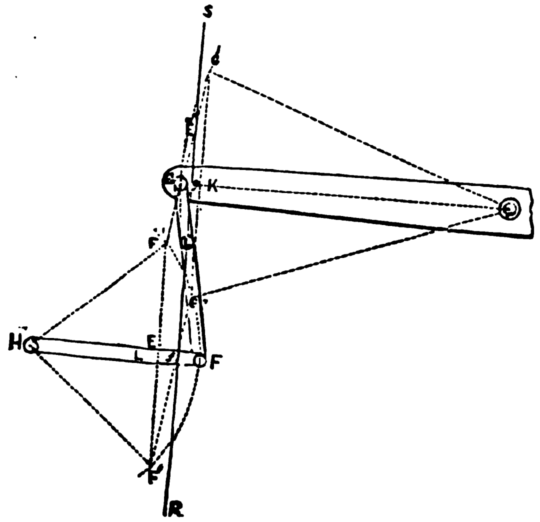


Fig. 2.

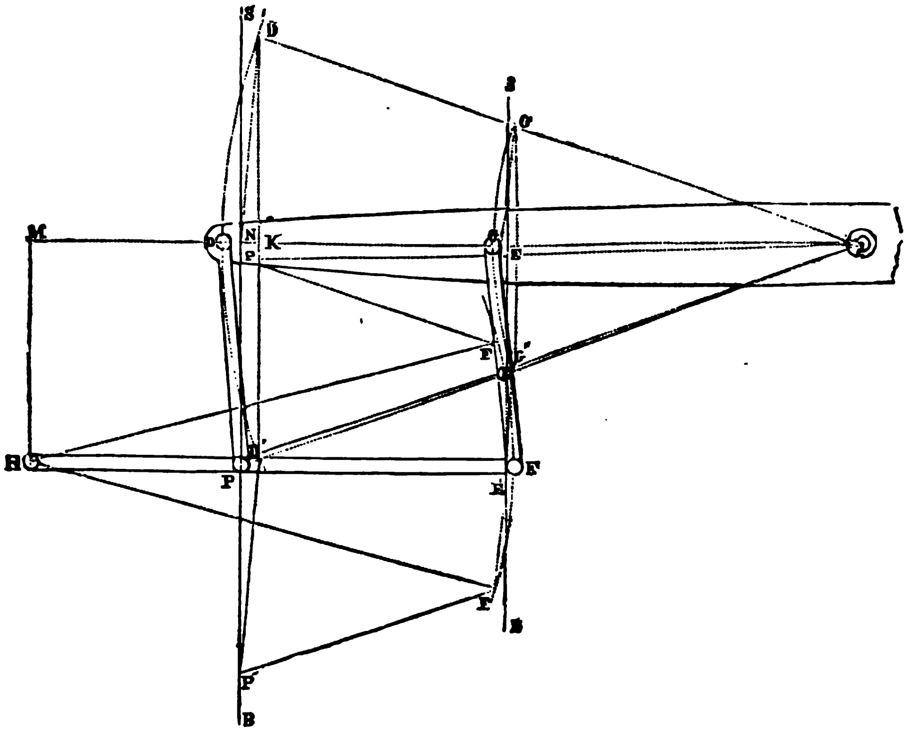


Fig. 3.

$$r=\frac{r'^2}{b-r'} \quad . \quad . \quad . \quad . \quad \textit{Figs. 3 and 4} \ldots \text{(B)}$$

$$r=\frac{a^2}{b+a}. \quad . \quad . \quad . \quad . \quad \textit{Figs. 3 and 4} \ldots \text{(C)}$$

$$r'=a-r \quad . \quad . \quad . \quad . \quad . \quad \textit{Figs. 3 and 4} \ldots \text{(C')}$$

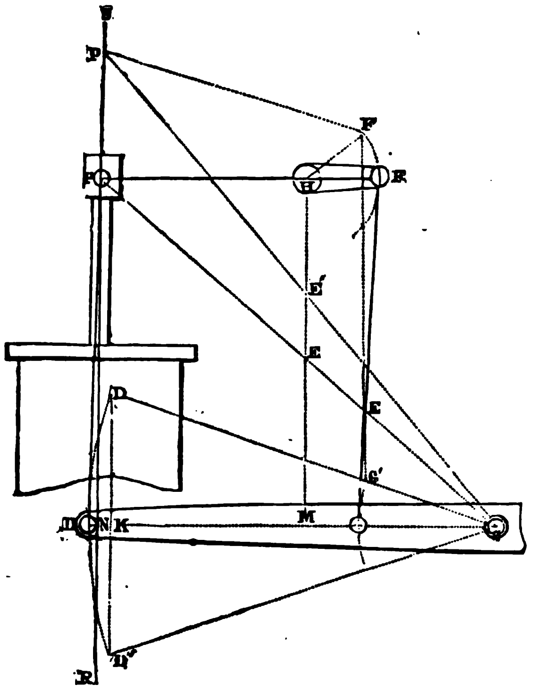
$$r=\frac{r'^2\, s}{b\,(s-c)-s\,r'} \quad . \quad . \quad . \quad \textit{Figs. 5 and 6.} \ldots\ldots \text{(D)}$$

$$^{*}\,r'=\frac{a^2\, s}{as+b\,(s-(c)} \quad . \quad . \quad . \quad \textit{Figs. 5 and 6} \ldots\ldots \text{(E)}$$

$$^{*}\,r'=a-r \quad . \quad . \quad . \quad . \quad \textit{Figs. 5 and 6} \ldots \text{(E')}$$

$$\left.\begin{array}{l} ^{*}c=\dfrac{(a+b)\,r-a^2}{b\,r}\,s \\ \text{Or } c=\left\{1+\dfrac{a-a^2}{b\,r}\right\}s \end{array}\right\} \quad . \quad . \quad . \quad \textit{Figs. 5 and 6} \ldots \text{(F)}$$

Fig. 4.



Rule I.—*In such a combination of two levers as is represented in Figs. 1 and 2, to find the length of radius bar required for any given length of lever C G, and proportion of parts of the link, G E and F E, so as to make the point E move in a perpendicular line.*

Multiply the length of G C by the length of the segment G E, and divide the product by the length of the segment F E. The quotient is the length of the radius bar.

Rule II.—(*Fig.* 2.) *The length of the radius bar and of C G being given, to find the length of the segment (F E) of the link next the radius bar.*

Multiply the length of C G by the length of the link G F, and divide the product by the sum of the lengths of the radius bar and of C G. The quotient is the length required.

Rule III.—(*Figs.* 3 *and* 4.) *To find the length of the radius bar (F H), the length of C G being given.*

Square the length of C G, and divide it by the length of D G. The quotient is the length required.

Rule IV.—(*Figs.* 3 *and* 4.) *To find the length of the radius bar, the horizontal distance of its centre (H) from the main centre being given.*

To this given horizontal distance, add half the versed sine (D N), of the arc described by the end of beam (D). Square this sum. Take the same sum, and add to it the length of the beam (C D). Divide the square previously found by this last sum, and the quotient is the length sought.

Rule V.—(*Figs.* 5 *and* 6.) *To find the length of the radius bar, C G and P Q being given.*

Square C G, and multiply the square by the length of the side rod (P D): call this product A. Multiply Q D by the length of the side lever (C D). From this product subtract the product of D P into C G, and divide A by the remainder. The quotient is the length required.

Fig. 5.

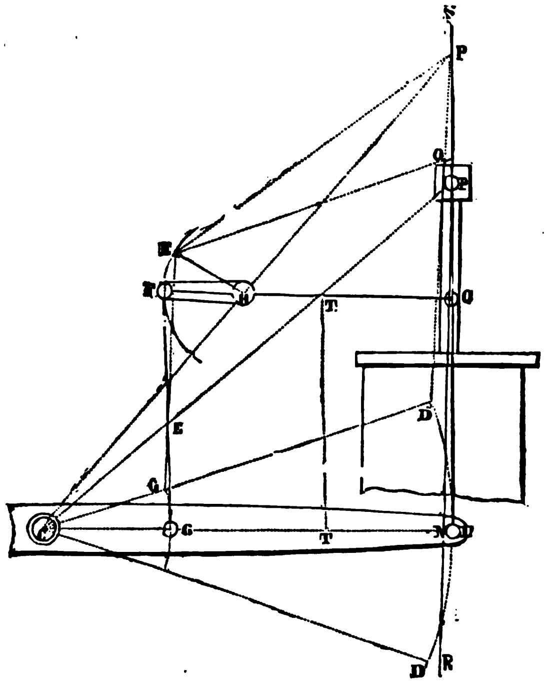
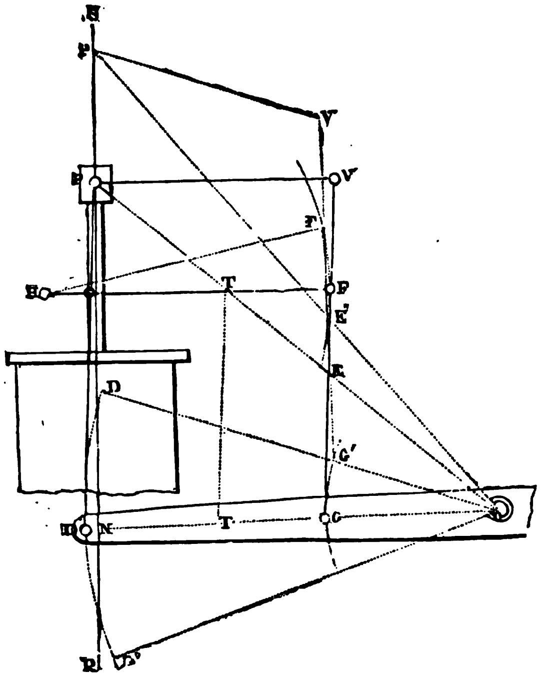


Fig. 6.



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* In formulas (E) (E′) and (F) a is to be taken equal to the horizontal distance of H from the main centre, $+\left(\frac{1}{2}\text{ vers. arc D' D D''}\times\frac{s-c}{s}\right)$. In formula (F) the value of $\frac{s-c}{s}$ cannot be accurately ascertained till the value of c has been calculated; but it can easily be taken by approximation, with sufficient exactness for the practical application of the formula.

Rule VI.—(*Figs.* 5 *and* 6.) *To find the length of the radius bar; P Q, and the horizontal distance of the centre H of the radius bar from the main centre being given.*

To the given horizontal distance, add half the versed sine* (D N) of the arc described by the extremity (D) of the side lever. Square this sum and multiply the square by the length of the side rod (P D). Call this product A. Take the same horizontal distance as before added to the same half versed sine (D N), and multiply the sum by the length of the side rod (P D): to the product add the product of the length of the side lever C D into the length of Q D, and divide A by the sum. The quotient will be the length required.

When the centre H of the radius has its position determined, rules 4 and 6 will always give the length of the radius bar F H. To get the length of C G, it will only be necessary to draw through the point F a line parallel to the side rod D P, and the point where that line cuts D C will be the position of the pin G.

In using these formulas and rules, the dimensions must all be taken in the same measure; that is, either all in feet, or all in inches; and when great accuracy is required the corrections given in Table (A) must be added to or subtracted from the calculated length of the radius bar, according as it is less or greater than the length of C G, the part of the beam that works it.

Examples.

1. Rule 4.—Let the horizontal distance (M C) of the centre (H) of the radius bar from the main centre be equal to 51 inches; the half versed sine D N = 3 inches, and D C = 126 inches. Then by the rule we will have

$$\frac{(51+3)^2}{51+3+126}=\frac{(54)^2}{180}=\frac{2916}{180}=16{\cdot}2 \text{ inches},$$

which is the required length of the radius bar (F H).

2. Rule 5.—The following dimensions are those of the Red Rover Steamer: C G = 32 D P = 94 Q D = 74 C D = 65 P Q = 20

By the rule we have, $A=(32)^2 \times 94 = 96256$ and

$$\frac{96256}{74 \times 65 - 94 \times 32}=\frac{96256}{1802}=53{\cdot}4,$$

which is the required length of the radius bar.

3. Rule 6.—Take the same data as in the last example, only supposing that C G is not given, and that the centre H is fixed at a horizontal distance from the main centre, equal to 83·5 inches. Then the half versed sine of the arc D′ D D″ will be about 2 inches, and we will have by the rule

$$A = (83{\cdot}5+2)^2 \times 94 = 705963{\cdot}5 \text{ and}$$
$$\frac{A}{85{\cdot}5 \times 94 + 65 \times 74}=\frac{705963{\cdot}5}{1284{\cdot}7}=54{\cdot}8 \text{ inches},$$

the required length of the radius bar in this case.

In both of the last two examples $\frac{C\,G}{H\,F}={\cdot}6$ nearly. The correction found by Table (A), therefore, would be 54 × ·027 = 1·458 inches, which must be subtracted from the lengths already found for the radius bar, because it is longer than C G. The corrected lengths will therefore be

in example 2 . . . . F H = 51.94 inches.
in example 3 . . . . F H = 53·34 „

PROPORTIONS OF THE DIFFERENT PARTS OF A STEAM ENGINE.

In constructing the different parts of a steam engine, and indeed of any other machine, it is desirable that they should be as light as is consistent with a due provision for safety, and with a due provision against the risk of accidents. The heaviness of the different parts brings along with it a corresponding amount of friction, and a corresponding amount of inertia, both of which must be overcome by the motive power before the machinery can be set in motion, and consequently before any useful effect can be derived from it. It is obvious, therefore, that the weight of the different parts of the engine is, to a certain extent, an evil, which can only be tolerated because it is the necessary concomitant of their strength, and consequently of a due provision against the risk of accidents. It is therefore desirable to reduce this evil as far as is consistent with that due provision which we have mentioned. We would not be understood to infer from these remarks, that the different parts of the steam engine should be constructed just of sufficient strength to resist the strains to which they are subjected. If this were to be the constant aim of an engineer who is conversant with the laws which govern the resistances of beams, we have no doubt but that the sarcastic remark, "the stability of the engine is inversely proportional to the theoretical skill of the engineer," would often be made. What we would be understood to infer is, that the strength of the different parts of the engine ought to be proportioned to the strains to which they are subjected. If one part of the engine be occasionally exposed to a strain double that of some other part, then it ought to have double the strength; if triple, triple; if quadruple, quadruple; &c. If we suppose the former part to have only $\frac{3}{2}$ the strength of the latter, then, on the supposition that it is subjected to a double force, $\frac{1}{4}$ of the strength of the latter is useless, at least in so far as regards exposure to accidents; on the supposition that it is subjected to a triple force, $\frac{1}{2}$ of the strength of the latter is useless; on the supposition that it is subjected to a quadruple force, $\frac{5}{8}$ of the strength of the latter is useless: and generally, on the supposition that it is subjected to a force m times as great, $\frac{2m-3}{2m}$ of the strength of the latter is useless. These are obvious; for, on the first supposition, the former would break when only $\frac{3}{4}$ of the strength of the latter was required, leaving the remaining $\frac{1}{4}$th useless; on the second supposition, the former would break when only $\frac{3}{6}$ or $\frac{1}{2}$ of the strength was exerted, leaving $1-\frac{1}{2}$ or $\frac{1}{2}$ useless; on the third supposition, the former would break when only $\frac{3}{8}$ of the strength of the latter was exerted, leaving $1-\frac{3}{8}$ or $\frac{5}{8}$ useless; and on the general supposition, the former would break when only $\frac{3}{2m}$ of the strength of the latter was exerted; leaving $1-\frac{3}{2m}$ or $\frac{2m-3}{2m}$, which would never be called into exercise. This superabundant strength is not merely useless; it is positively prejudicial, inasmuch as it brings along with it additional expense, and, what is more serious, an unnecessary and prejudicial weight. We therefore proceed to investigate the proper strength for some of the principal parts of the engine. The investigation will depend upon those laws which regulate the resistances of beams to fracture, to compression, to tension, to torsion, &c. These laws, we may observe, are derived from theory, and abundantly confirmed by experiment, so that we have no doubt with respect to them. In their application, however, a difficulty occurs in determining the proper values of the constants, which vary for different materials or even for different qualities of the same material, and which can only be determined by numerous experiments. It is obvious, also, that the proper strength of the different parts depends principally upon the pressure exerted in the cylinder upon the piston; and this depends upon the diameter of the cylinder and the pressure of the steam in the boiler, or rather the greatest power which it may acquire before escaping at the safety valve. The proper strength of some of the parts also depends upon the length of the stroke; as, for example, in a marine engine, the diameter of the paddle shaft journal, and the exterior diameter of the large eye of the crank, &c. We may remark, that the parts of marine engines ought in general to possess a greater strength, since accidents with them are more serious and more difficult to repair.

Before proceeding farther, it may be necessary to give a few general propositions upon the resistances of solid materials to different sorts of strains.

A piece of solid matter may be exposed to four different kinds of strains, which are different in the manner of their operation.

I. It may be acted upon by a tensile force, which tends to pull it asunder; as, for example, in the case of ropes, stretchers, king-posts, tie-beams, &c.; or, in a steam engine, the piston rod of a single-acting engine, the connecting rod, &c.

II. It may be acted upon by a force which tends to break it across; as in the case of a joist or lever of any kind; and, in a steam engine, the crank, the main beam, &c.

III. It may be acted upon by a force which tends to wrench or twist it; as in the case of the axis of some wheels, &c.; or, in a land engine, the shaft of the fly wheel; or, in a marine engine, the paddle shaft.

IV. It may be crushed, as in the case of pillars, posts, and truss beams; and, in a steam engine, the piston rod when it is a double-acting engine, parallel motion rods, air pump and force pump rods, and the like.

Each of these forces is resisted by the cohesion of the material, differently modified for the particular species of force. When they are increased to a certain extent the force of cohesion is so far overcome as to allow the material to take a new shape; for example, when a beam is subjected to a considerable transverse force it is often observed to take a curvilinear form. If the applied force be not increased above a certain limit, then, immediately upon its removal, the beam resumes its former shape; but if the applied force be greater than a certain limit, then, although it be removed, the beam does not resume its former shape, but takes permanently a shape different from its original one. The beam is then said to have taken a "set;" and it is remarkable that after a beam has once taken a set it cannot resist so great a force as previously without undergoing permanent derangement. These remarks are not confined to those materials of which beams are usually constructed—they are applicable to all sorts of material. If we take a quantity of clay, and form it into a rod, and apply to the rod a tensile force, then the tensile force will stretch the rod; but if it be not greater than a certain limit, upon its removal the rod will resume its former length: if, however, it be greater than a certain limit, the rod will take a length different from its original one. The same process may be renewed, and the rod will take up a series of sets, each set requiring a smaller force to cause permanent change than the previous one. The force of cohesion varies for different materials, and is constant for the same material; or, we should rather say, it is constant for the same quality of the same material. Its efficacy in resisting an applied force depends greatly upon the shape of the body: thus, a beam of a certain shape will perhaps only resist a force one half that which another beam, of the same material and of the same quantity of material, but of a different shape, will resist. Its efficacy also depends upon the manner of applying the force; that is to say, whether it is applied as a tensile force, or as a crushing force, or as a breaking force, or as a twisting force: thus, a beam may resist a force of 20 cwt. when applied as a tensile force, and not be able to resist a force of 1 cwt. when applied as a breaking force. We proceed to consider shortly each of these forces in succession.

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* If great accuracy is required, in place of D N in this rule take D N multiplied by D Q and divided by P Q.

I. *Tensile Force.*

This is the simplest of all strains, and indeed the others are only modifications of it. It is therefore proper to consider it first, since this will be in a manner introductory to the investigation of the others. We have previously remarked that it is the cohesion of the materials which resists the forces. In the case of a tensile force, the force of cohesion is directly opposed to it, with very little modification of its action by any particular circumstances. This renders the investigation very easy. When a cylindrical or prismatic body, such as the piston rod of a single acting steam engine, is acted upon by a tensile force at one extremity, the body is in a state of tension throughout all its length. It is easy to show that the tension is equal at all the points in the length: indeed this follows as a consequence from that equality of action and reaction which experiment shows to subsist whenever bodies act upon one another. The first plate or layer of matter at the extremity of the body is kept in equilibrio by two opposite forces—the tensile force tending to separate the layer from the body, and the force of cohesion, which connects the layer to the body. These forces are directly opposite; and all experiment shows us that, before two directly opposite forces can balance one another, they must be equal. Again, the second plate or lamen is kept in equilibrio by two forces—the cohesive force uniting the first and second lamina, and which we have just shown to be equal to the tensile force; and the cohesive force uniting the second lamen and the third. These forces must in like manner be equal. It is obvious that, by proceeding in this manner, we may show universally that the part of the cohesive force which is called into action in order to resist the tensile force at the extremity is always exactly equal to the tensile force.

Since all the parts are thus equally on the stretch, it follows that the strain in any transverse section is the same, as also in every point of that section. Hence the capability of a prismatic body to resist tension is proportional to the area of the minimum tranverse section. If f denote the maximum weight in pounds which a bar of one square inch in section can bear without undergoing permanent derangement, and A denote the area in square inches of a transverse section of another prismatic bar, or the area in square inches of the minimum transverse section of a bar of any other shape; then the greatest weight which that bar can bear without rupture is fA lbs. The number denoted by f, of course, differs for different materials. It can only be found by experiment. The only materials which we shall have occasion to consider, are cast iron, malleable iron, and tempered steel; and for each of these materials f has been determined with an accuracy sufficient for our purpose. It has been found that

for cast iron $f=15{,}300$ lbs.
for malleable iron $f=17{,}800$ lbs.
for tempered steel $f=45{,}000$ lbs.

It is the united force of cohesion immediately before the disunion of the first particles, or the force which connects two adjoining lamina together before the tensile force separates them, that we call the *strength of the section*. It is also very properly called the *absolute strength*, since it is exerted in its simplest form, and not modified by any relation to other circumstances. We may remark, that the different values we have given to f for the different metals ought not to be regarded as perfectly accurate. They are deduced from experiment, and ought to be considered as no more than general values, or the averages of many particular trials. The irregularities are very great, since no substances are constant in their texture and firmness. Metals are affected in their tenacity by a thousand circumstances, such as their purity, the heat with which they were melted, &c. In the application of these numbers all danger will be obviated by making the particular part subjected to strain a little greater than what theory would indicate.

II. *A Breaking Force; or, a Force tending to break the Body across.*

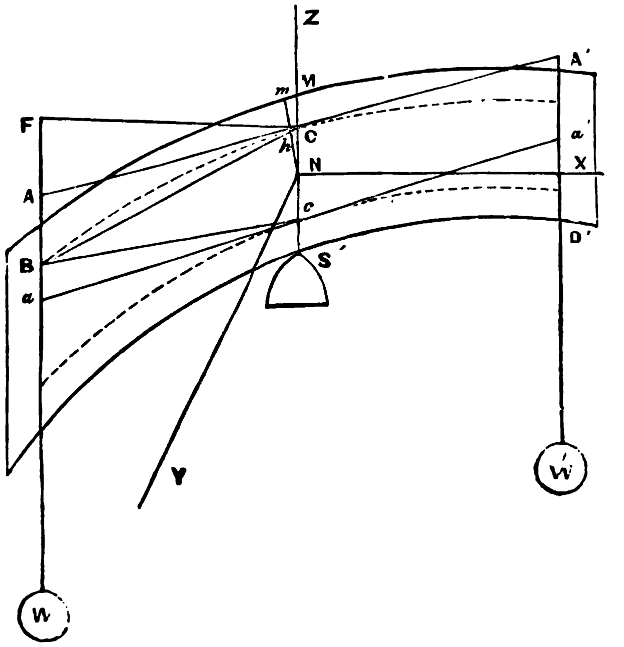
This is the most usual, and at the same time the greatest, force to which materials are subjected. It is seldom, however, that it occurs in a perfectly simple form. When a beam projecting horizontally from a wall has a force applied at its extremity, the beam is commonly broken near the wall, and the intermediate part has in the mean time performed the function of a lever; so this is not a case of simple transverse fracture, but is complicated with the action of a lever. An example of a bar subjected to a simple transverse fracture, occurs in the pin which forms the joint of a pair of pincers or scissors. As cases of this kind occur but rarely in machines, we shall not stay to examine them minutely, and may content ourselves with saying, that in this case the strength of the piece is proportional to the area of the section. We proceed to the much more common and much more important case where the agency of the lever intervenes.

Before commencing the theoretical investigation of the strength of beams when opposed to a transverse strain, we may remark that our knowledge of the manner in which the direct cohesion of the material is brought into action is very imperfect. The celebrated Galileo, to whom the physical sciences are so much indebted, was the first who connected this subject with mathematical principles, and endeavoured to trace the law of strength which different bodies possess, in proportion to their length, breadth, depth, form, and position. He arrived at the correct conclusion, that when a beam is pulled in the direction of its length, its absolute cohesion is proportional to the area of the transverse section. When he proceeded to find the efficacy of a beam in resisting a transverse strain, he immediately fell into mistakes. Indeed this investigation is much more difficult, since we do not see so clearly how the resisting forces exert themselves, nor in what degree. Galileo proceeded upon the hypothesis, that if a beam were supported at its extremities, and loaded by a weight at the middle, that all the fibres of the beam would exert equal resistances to prevent fracture, and that when these were overcome, the section would tend to turn about that boundary of it in contact with the weight. Following out the consequences of this theory, he arrived ultimately at the following conclusion. When a beam is fixed solidly in a horizontal position in a wall, or other immoveable mass, the resistance of the integrant fibres is proportional to their sum multiplied into the distance of the centre of gravity of the area of fracture from the lowest point. The results of this theory are certainly very simple; but, unfortunately, the hypothesis is not conformable to what takes place in nature. It assumes, for example, that the beam is perfectly inflexible, except at the point of fracture: now we know that no beam is perfectly inflexible. Again it assumes that the fibres are inextensible and incompressible; whereas every experiment shows us that the fibres are both extensible and compressible. The theory of Galileo having these radical defects, it necessarily happened that when it was tested by practical experiments, the theoretical strength was found to differ widely from the actual strength. The first person who drew attention to these defects was Mariotte. The few hints which he suggested, in a work entitled "Traité du Mouvement des Eaux," attracted the attention of Leibnitz, who propounded a new theory. The theory of Leibnitz coincided with that of Galileo in so far as regards the axis about which the section would turn; both making that axis to pass through the lowest point in the section of fracture when the beam is supported at one end, and the highest when the beam is supported at both ends; but it differed from it as regards the equal resistances of the fibres throughout the whole fracture. Leibnitz had frequently remarked that the rupture of a body, whatever it may be, is always preceded by a certain degree of deflection, from which he concluded that every body was composed of extensible fibres; and assuming the principle first laid down by Dr. Hooke, viz., "ut tensio sic vis," he concluded that every fibre exerted a force proportional to its quantity of extension, or, which is the same, proportional to its distance from the line about which the beam was supposed to turn; but he still considered the fibres to be incompressible, and consequently that the beam turned about its lowest point. This theory, although conformable to nature in some respects, is deficient in others. It, however, approximates much nearer to the truth than the theory of Galileo. It is a remarkable coincidence, that although these two theories differ from one another, and from nature, in so far as regards the real strength of beams having a rectangular transverse section in resisting a tranverse force, they both lead to the same inference, viz., "that the law of resistance is as the breadth multiplied by the square of the depth," an inference which has been abundantly confirmed by experiment. James Bernoulli proposed a third theory. This philosopher observed, that at the instant a body is broken across by a transverse strain, a part of the fibres is in a state of extension, and a part in a state of compression. It will be observed that the latter fact is a circumstance which had never before been introduced into the consideration of the question. Bernoulli assumed that the beam had a tendency to turn about a line entirely within the section which separated the extended fibres from the compressed fibres. This line is generally called the neutral axis. The theory of Bernoulli prevails to the present day. All the difficulty experienced upon the subject is to determine the exact position of the neutral axis. Having given this short sketch of the different theories proposed upon this subject, we proceed now to determine the resistances which beams of different shapes offer to a cross strain. In the investigation we will assume as true the theory of Bernouilli. His theory carries the air of truth, and its results are confirmed by experiment.

Let the beam A A′ D′ D be supported upon a fulcrum at S in equilibrio. Suppose, for the present, that the beam is acted upon by no other forces than W and W′, which have produced their full effect in deflecting the beam; suppose also the vertical section at M S to be divided into an infinite number of filaments or fibres; consider C to be the situation of one of the filaments in the upper part of the beam, and A A′ a tangent to the curvature of the filament at C: it is obvious that the forces tending to separate the filament at C must be equal, and they must act in the tangent; so that the strain which produces rupture is obviously a tensile one. Again, B A is the direction of the weight. Hence, from well-known statical principles, we have AC : AB :: tensile force on filament at C : its effect in sustaining the weight W. Denoting, for the present, the tensile force on filament at C by S, we have, effect of the filament in sustaining $W=S\frac{AB}{AC}$.

Now, according to the theory of Bernoulli, the weights will compress the lower part of the beam. Let *c* be a compressed filament, having the same area as the filament at C, and situated at the same distance from the lower surface that the filament at C is from the upper surface; let also *a a'* be a tangent to the filament at *c*, and consequently parallel to the tangent A A'; then, from well-known statical principles, we have *a c* : *a*B : : resistance to compression at *c* : effect of the filament in sustaining the weight W.

Fig 7.



Now, it is proved from experiment that portions of the same matter, of equal area, resist extension and compression with equal forces. We infer, therefore, that the effect of the filament at *c* in sustaining the weight W $= S\frac{aB}{ac}$. The effect of both the filaments in supporting the weight will therefore be $= S\left\{\frac{AB}{AC}+\frac{aB}{ac}\right\}$. Hence, since A C $=$ *a c*, and AB $+$ *a* B $=$ A *a*—C *c*, we have the effect of both the filaments in supporting the weight $= S\frac{Cc}{AC}$. As one side of the beam suffers extension and the other compression, there will be a filament at some point of the depth which will neither be compressed nor extended. This filament is what we have elsewhere styled the neutral axis. The extension and compression of a filament will obviously be at its distance from this neutral axis. Assuming the principle Dr. Hooke so clearly laid down, "ut tensio sic vis," a law which experiment confirms, it follows that the stress upon a filament is proportional to its distance from the neutral axis. The principal difficulty in determining the strength of a beam, when opposed to a transverse strain, consists in the determination of the position of the neutral axis. Indeed the position of the neutral axis cannot properly be determined by theory at all; it is more properly a matter of experiment. When a body is symmetrical about a line, we may assume that line as the neutral axis. Sundry modern experiments seem to show that the neutral axis is in general nearer to the upper surface than to the lower; but in no case does the position of the neutral axis differ much from the position of the natural axis of the body. We have shewn that the effect of two filaments is as the distance between them; the effect of either will therefore be as its distance from the neutral axis; for the filaments being equal, and the strain on them equal, the axis will be at the middle of the distance between them; and the effect of both being measured by the whole depth, that of one of them will be measured by half the depth. Hence the effect of the filament at C $= S\frac{CN}{AC}$. From the similarity of the triangles N *h* C and F A C we conclude that $\frac{CN}{AC}=\frac{Nh}{FC}$. Hence the effect of the filament $= S\frac{Nh}{FC}$. Let S' denote the stress upon an equal filament at *m*; then since the stress is proportional to extension, and extension proportional to the distance from neutral axis, we have

$$Nm : Nh :: S' : S = \frac{Nh}{Nm}S'.$$

Hence effect of filament at C $= S'\frac{Nh^2}{Nm.\,FC}$

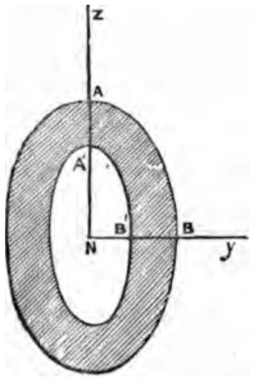
Let the area of a vertical section of the filament be denoted by *d* A, then when the weight is just about to break the beam, or rather to cause permanent derangement $S' = f\,dA$. In this case the effect of the filament at C' $= f\frac{Nh^2}{Nm\cdot FC}dA$. Now the total weight which the beam can resist without permanent derangement is the sum of all these effects. Hence taking N as axis of co-ordinates, the axes of X parallel to F C' the length, the axis of Y in the direction of breadth, and the axes of Z in the direction of the depth; denoting also the depth in inches by *d*, or 2 N *m* $=$ *d*, and the length F C in inches by *l*, then $W = \frac{2f}{ld}\int\int z^2\,dz\,dy$. In this the integrals must be taken between the proper limits.

As an example of the application of this formula, we may proceed to determine the lateral strength of a hollow elliptical cylinder.

Let the accompanying figure represent a vertical section of this cylinder; N the position of the neutral axis; N Z as before, the depth, or the direction in which the force is applied; and N Y the breadth. Put N A $= a$, N $A_1 = a_1$, N B $= b$, N $B_1 = b_1$: then the equations of the two ellipses are

$$\left(\frac{y}{a}\right)^2+\left(\frac{z}{b}\right)^2=1,\ \left(\frac{y_1}{a_1}\right)^2+\left(\frac{z_1}{b_1}\right)^2=1.$$

Fig. 8.



These may be put under the form

$$y=\frac{a}{b}\sqrt{b^2-z^2},\ \text{and}\ y_1=\frac{a_1}{b_1}\sqrt{b_1^2-z_1^2}$$

Now the strength of the beam may obviously be found by first determining the strength, considering it as a solid, and then subtracting the strength of the hollow part. Hence our formula becomes

$$W=\frac{2f}{ld}\int_{-y}^{y}\int_{-b}^{b}z^2\,dz\,dy-\frac{2f}{ld}\int_{-y_1}^{y_1}\int_{-b_1}^{b_1}z_1^2\,dz_1\,dy_1$$

$$=\frac{4f}{ld}\cdot\frac{a}{b}\int_{-b}^{b}\sqrt{b^2-z^2}\,z^2\,dz-\frac{4f}{ld}\cdot\frac{a_1}{b_1}\int_{-b_1}^{b}\sqrt{b_1^2-z_1^2}\,z_1^2\,dz_1$$

But

$$\int_{-b}^{b}\sqrt{b^2-z^2}\,z^2\,dz=b^2\int_{-b}^{b}\frac{z^2\,dz}{\sqrt{b^2-z^2}}-\int_{-b}^{b}\frac{z^4\,dz}{\sqrt{b^2-z^2}}$$

or putting $z = b\,Z$

$$\int_{-b}^{b}\sqrt{b^2-z^2}\,dz=b^4\int_{-1}^{1}\frac{Z^2\,dZ}{\sqrt{1-Z^2}}-b^4\int_{-1}^{1}\frac{Z^4\,dZ}{\sqrt{1-Z^2}}$$

But it is shown by writers on the Integral Calculus that

$$\int_{-1}^{1}\frac{Z^{2m}\,dZ}{\sqrt{1-Z^2}}=\frac{1.3.5\ -\ -\ -\ (2m-1)}{2.4.6\ -\ -\ -\ -\ 2m}\pi$$

Hence

$$\int_{-b}^{b}\sqrt{b^2-z^2}\,z^2\,dz=b^4\frac{\pi}{2}-b^4\frac{3\pi}{8}=\frac{\pi}{8}b^4;$$

and therefore

$$W=\frac{4f}{ld}\times\frac{a}{b}\times\frac{\pi}{8}b^4-\frac{4f}{ld}\times\frac{a_1}{b_1}\times\frac{\pi}{8}b_1^4$$

$$=\frac{\pi f}{2ld}\left\{ab^3-a_1b_1^3\right\}$$

This result is general, and we may derive from it some particular results. Suppose the ellipses are similar; put $a_1 = n\,a$, and $b_1 = n\,b$; then we obtain

$$W=\frac{\pi f}{2ld}ab^3\left\{1-n^4\right\}=\frac{\pi f}{4l}ab^2\left\{1-n^4\right\}$$

Suppose, in addition, that the ellipses become circles, or $a = b = r$; then

$$W=\frac{\pi f}{4l}r^3\left\{1-n^4\right\}=.7854\frac{f}{l}r^3\left\{1-n^4\right\}$$

In applying this formula to particular cases, it is necessary to remember that the dimensions are supposed to be taken in inches, and that the answer is in lbs. To adapt it to other dimensions, it is necessary to make corresponding substitutions.

Before leaving this example, we may take occasion to remark that a considerable accession of strength is always obtained by making the shaft hollow, and at the same time preserving an equal quantity of matter. This may be demonstrated as follows. The area of exterior circle $=\pi r^2$, and the area of interior circle $=\pi n^2 r^2$; hence the area of the section $=\pi r^2 (1-n^2)$. Let r_1 denote the radius of a circle equal in area to the area of the section, then r_1 will be obtained from the equation $\pi r_1^2 = \pi r^2 (1-n^2)$, or $r_1 = r\sqrt{1-n^2}$. Now the strength of a solid cylindrical beam, the radius of whose section is r_1, is found from the general value by taking $n=o$; denoting the weight by W^1, we have

$$W^1 = \frac{\pi f}{4\,l}\, r_1^3 = \frac{\pi f}{4\,l}\, r^3\, (1-n^2)^{\frac{3}{2}}.$$

Hence,

$$W : W^1 :: 1-n^4 : (1-n^2)^{\frac{3}{2}};\ \text{or}$$

$$W : W^1 :: 1+n^2 : \sqrt{1-n^2}.$$

This analogy shows us that W is always greater than W^1. Hence, whenever it is an object to gain strength without increasing the weight, this will be accomplished by increasing the diameter of the vertical section, and making the tube hollow. We may observe a beautiful application of this principle in the construction of the human frame. Those bones which are often subjected to great lateral strains are hollow and have large diameters; so that, whilst they impart stability to the whole mass, they do not impede its active motions by their weight. The same contrivance may be observed in the construction of the different parts of birds. In the case of malleable iron beams, the neutral axis lies nearer the bottom than the top, as malleable iron resists extension better than it resists compression. Hollow malleable iron beams should therefore be stronger on the upper than on the under side, being the reverse in this respect of beams of cast-iron.

III. The force may have a tendency to twist the body round.

We have previously stated, that the efficacy of any material in resisting a force applied in any direction, arose from the force of cohesion subsisting between the particles of that material. We have seen the different ways in which this force of cohesion is called into existence, when the applied force is tensile and when it is transverse. It is more difficult to explain by what modification of the force of cohesion a beam is enabled to resist a twisting force. But although we cannot pretend to have any very distinct conception of that modification of the cohesion of a body by which it resists this species of strain, we can have no doubt that, when all the particles are similarly situated and act alike, the resistance must be proportional to their number. Hence, supposing an indefinitely thin tube to possess a transverse section in which the particles cohere more feebly than in any other section, then if this tube be grasped in both hands, and the two parts be twisted round the axis in opposite directions, as we would twist the two joints of a flute, it is obvious the tube would fail in this transverse section. Now the transverse section is a circle, and all the particles in that section are similarly situated, and therefore act alike; so that the total resistance will be as the circumference: denoting the radius of the section by r, and the breadth by $d\,r$, then

$$\text{total resistance} \propto 2\pi\, r dr = 2\pi C r \times dr.$$

We can now suppose another tube within this, and a third within the second, and so on till we reach the centre. If we suppose the particles of each successive ring exerted the same force, then C is constant; and the total resistance of a cylinder would be equal to $2\pi C \int_o^r r dr = \pi C r^2 \propto r^2 \propto$ surface of the section. But when a cylinder is twisted in the manner we have supposed, it is obvious that an external particle will suffer a greater circular extension than an internal particle. It is impossible to determine *à priori* the law according to which the circular extensions are regulated. We may suppose that the extension of a particle is proportional to the nth power of its distance from the axis of the cylinder; or $C \propto r^n = C' r^n$. Then the resistance of the cylinder $= 2\pi C' \int_o^r r^{n+1} dr = \frac{2\pi C' r^{n+2}}{n+2}$. In the case of a transverse force, we mentioned that the strain upon a filament was proportional to its distance from the neutral axis; it seems probable that this should be the law in the case of the twisting force also. Assuming this law, we have $n=1$, and

$$\text{the resistance of cylinder} = \tfrac{2}{3}\, C' r^3 \propto r^3 \propto d^3.$$

We cannot say that we have demonstrated this, since we have assumed arbitrarily that the extension is proportional to the distance from the axis; at the same time, no proportion is more probable. But the best test of the accuracy of our result is furnished by experiment. Experiments show that the resistance to tension of a cylindrical tube is proportional to the cube of its diameter, or to the cube of its radius. It is obvious that the resistance to torsion will also depend upon the nature of the material, so that we have

$$\text{the resistance of a cylinder} \propto f r^3 \propto d^3.$$

IV. The force may be so applied as to have a tendency to crush the body.

It is still more difficult than in any of the preceding cases to conceive by what modification of the force of cohesion a body is enabled to resist a crushing force. When the length of a column is much greater than its breadth, then, on the application of a crushing force, the column bends to one side before it breaks. When the column is too short to bend, its strength is only limited by the force which would crush it. Theory has as yet furnished very little assistance in determining the force necessary to crush a column which is too short to bend. The first person who turned his attention to this subject was Euler, who published his "Strength of Columns" about the year 1757. He arrived at the conclusion, that the strength of a column to resist a crushing force was proportional to the fourth power of the diameter. We may mention that his theory is founded upon an entirely gratuitous assumption, and consequently no dependence can be placed upon its results, except they are found to agree with experiment. Now, all experiments upon this subject show that the strength of a cylindrical column does not increase in so high a ratio as the fourth power of the diameter. It has also been advanced, that the strength of a column is proportional to the transverse section, so that if the column be cylindrical, its strength is proportional to the square of the diameter. Experiments, however, show that the strength increases in a higher ratio than the square of the diameter. It is very difficult to experiment upon this subject, in consequence of the necessity of using such very large forces to crush a comparatively small column; hence it is that the experiments published differ so very much. They seem to show, if any thing at all, that the strength of a cylindrical column is proportional to the cube of the diameter. We are, fortunately, under no necessity of considering this case at present, since all the parts of a steam engine which are subjected to a crushing force are so long compared with their breadth as to be liable to flexure. It is the flexure which a crushing force produces in a long column that ought to be guarded against. Now it is a general rule, sanctioned by experience, never to load a column with a force greater than its elastic force. Thus, if the column be cylindrical, and the diameter of its transverse section equal to d inches, then the greatest load which can be placed upon it with safety is $\cdot 7854 \times f \times d^2$. This is the greatest load that can be placed upon it with safety, even when it acts exactly in the axis of the cylinder. When the force acts at some point different from the axis, then its efficacy in bending the column is very much increased, and this efficacy continues to increase with the distance between the axis and the point of application of the force. This is a circumstance which ought to be particularly attended to in proportioning the diameters of several of the rods used in the mechanism of a steam engine, for it is obvious that in none of these rods does the crushing force always act in the axis; on the contrary, in most of them the compressing force occasionally acts in the surface of the rod, or at the distance of half the diameter from the axis. We might here advance some theoretical considerations for estimating the amount of the increase of the efficacy of the force in bending the column when acting at the surface, above its efficacy in bending the column when acting at the axis; but, as there is considerable difficulty in their conception, and very little dependence can be placed upon the results, we shall omit these speculations, and shall conclude these remarks by mentioning as a general result of such considerations, that a cylindrical rod whose length greatly exceeds its breadth d, ought never to be loaded with a weight greater than $\frac{1}{8} f d^2$, unless the weight always acts very nearly in the axis of the cylinder.

We now proceed to determine the proportions for several of the principal parts of a steam engine. It is obvious that the dimensions of all the parts ought to depend upon the pressure of the steam in the boiler, or rather the greatest pressure it can attain before forcing open the safety valve. In the following investigations we denote this pressure by P. In the rules we have given, it is desirable to take P considerably larger than the pressure before escaping at safety valve. A good practice would be to take it always double of this pressure.

To find the strength of the arms of beams, cranks, &c.

The vertical section of beams, cranks, &c. are generally rectangles. It will therefore be necessary to apply the formula for transverse strength.

$$W = \frac{2f}{d\,l} \int\!\!\int z^2\, d\,z\, d\,y.$$

Let b denote the breadth in inches, then

$$W = \frac{2f}{d\,l} \int_{-\frac{b}{2}}^{\frac{b}{2}} \int_{-\frac{d}{2}}^{\frac{d}{2}} z^2\, d\,z\, d\,y = \frac{2f\,b}{d\,l} \int_{-\frac{d}{2}}^{\frac{d}{2}} z^2\, dz.$$

$$= \frac{2}{3}\frac{f\,b}{d\,l}\left\{ \left(\frac{d}{2}\right)^3 - \left(\frac{-d}{2}\right) \right\} = \frac{f\,b\,d^2}{6\,l}.$$

Therefore $f\,b\,d^2 = 6\,W\,l.$

In this formula the dimensions are all in inches. If L denote the length in feet, then the formula becomes $f\,b\,d^2 = 72\ W\ L$. We learn from this that the strength of the beam or crank depends much more upon the depth than the thickness, and therefore it is desirable to increase the depth as much as is consistent with other considerations. It may be assumed, however, as a general principle, that a beam of uniform thickness should never have its depth greater than sixteen times its thickness, because otherwise it is liable to overturn. Assume, therefore, $16\ b = d$, then the formula becomes $f\ d^3 = 16 \times 72 \times W \times L = 1152 \times W \times L$. Denote the pressure on square inch of the steam in the boiler when the steam has acquired an elasticity sufficient to force open the safety valve by P, and the diameter of the cylinder by D; then the greatest value of W is $\frac{\pi}{4}\ P \times D^2$. Suppose also $12\ L = n\ D$; then our formula becomes $12\ f\ d^3 = \cdot7854 \times 1152 \times n\ P \times D^2$, which, by reduction, becomes $f\ d^3 = 75\cdot399 \times n \times P \times D^3$. Therefore finally $d = D^3\sqrt{\frac{75\cdot399 \times n \times P}{f}}$

For cast iron $f = 15300$
malleable iron $f = 17800$

By substituting these values our formula becomes,

$$\text{For cast-iron} \quad d = D\left\{\frac{n\ P}{202}\right\}^{\frac{1}{3}}$$

$$\text{malleable iron } d = D\left\{\frac{n\ P}{236}\right\}^{\frac{1}{3}}$$

We have reduced the formula principally with reference to the main beam of an engine. It may be put into the following rule:—

Rule. — *To find the depth of the main beam at the centre.—Divide the length in inches from the centre of motion to the point where the piston rod is attached, by the diameter of the cylinder in inches; multiply the quotient by the maximum pressure in pounds per square inch of the steam in the boiler; divide the product by* 202 *for cast iron, and* 236 *for malleable iron: in either case the cube root of the quotient multiplied by the diameter of the cylinder in inches gives the depth in inches of the beam at the centre of motion. To find the breadth at the centre.—Divide the depth in inches by* 16; *the quotient is the breadth in inches.*

Example. — An engine beam is three times the diameter of the cylinder, from the centre to the point where the piston rod acts on it; the force of the steam in the boiler when about to force open the safety valve is 10 lbs. per square inch. Required the depth and breadth when the beam is of cast iron.

In this case $n = 3$, and $P = 10$, and therefore

$$d = D\left\{\frac{30}{202}\right\}^{\frac{1}{3}} = \cdot53\ D.$$

$$\text{The breadth} = \frac{\cdot53}{16}\ D = \cdot03\ D.$$

It will be observed that our rule gives the least value to the depth. In actual practice, however, it is necessary to make allowance for accidents, or for faultiness in the materials. This may be done by making the depth greater than that determined by the rule; or perhaps more properly by taking the pressure of the steam much greater than it can ever possibly be. As for the dimensions of the other parts of the beam, it is obvious that they ought to diminish towards the extremities; for the power of a beam to resist a cross strain varies inversely as its length. The dimensions may be determined from the formula $f\,b\,d^2 = 6\ W\ l$.

To apply the formula to cranks, we may assume the depth at the shaft to be equal to n times the diameter of the shaft; hence if $m \times D$ be the diameter of the shaft, the depth of the crank will be $n \times m \times D$. Substituting this in the formula $f\,b\,d^2 = 6\ W\ l$, and it becomes $f\,b \times n^2 \times m^2 \times D^2 = 6\ W\ l$. Now, as before, $W = \cdot7854 \times P \times D^2$, so that the formula becomes $f \times b \times n^2 \times m^2 = 4\cdot7124 \times P \times l$. The value of n is arbitrary. In practice it may be made equal to 1½ or 1·5. Taking this value, then, for cast iron, the formula becomes $15300 \times b \times \frac{9}{4} \times m^2 = 4\cdot7124 \times P \times l$, or $7305\ m^2\ b = P\ l$; but if L denote the length of the crank in feet, the formula becomes $609\ m^2\ b = P\ L$, and $\therefore b = P \times L \div 609\ m^2$. This formula may be put into the form of a rule, thus:—

Rule. — *To find the breadth at the shaft when the depth is equal to* 1½ *times the diameter of the shaft.—Divide the square of the diameter of the shaft in inches by the square of the diameter of the cylinder; multiply the quotient by* 609, *and reserve the product for a divisor; multiply the greatest elastic force of the steam in lbs. per square inch by the length of the crank in feet, and divide the product by the reserved divisor: the quotient is the breadth of the crank at the shaft.*

Example. — A crank shaft is ¼ the diameter of the cylinder; the greatest possible force of the steam in the boiler is 20 lbs. per square inch; and the length of the shaft is 3 feet. Required the breadth of the crank at the shaft when its depth is equal to 1½ times diameter of the shaft.

In this case $m = \frac{1}{4}$, so that reserved divisor $- \frac{609}{16} = 38$; again, elastic force of steam in lbs. per square inch $= 20$ lbs.: hence width of crank $= \frac{3 \times 20}{38} = 1\cdot6$ inches nearly.

The Strength of Shafts. — Shafts are in general so supported as to render the lateral stress as small as possible; hence we have only to consider the resistance to torsion. No part of the shaft should be less than the bearings or journals; and therefore it will be sufficient to determine their diameter. We have previously mentioned, that the resistance which a cylindrical shaft offers to a twisting force is proportional to the cube of its diameter. This result may be arrived at by theoretical considerations; but, what is more to be depended upon, it is confirmed by experiment. Let W denote the greatest weight acting at the extremity of the crank, and R the length of the crank, or radius of wheel; then we have $R \times W \propto$ (diameter of shaft³).

Suppose the shaft makes n revolutions for each double stroke of the piston; suppose also $R = m\ D$; then we have

$$m\ D \times W \propto n\ (\text{diameter})^3\text{; or,}$$
$$m\ D \times W \propto \ \times n \times d^3.$$

As before, $W = \cdot7854\ P \times D^2$; and therefore $\cdot7854\ m \times P \times D^2 = c \times n \times d^3$, which gives $d = D\left\{\frac{\cdot7854 \times m \times P}{c \times n}\right\}^{\frac{1}{3}}$. The constant c varies for different materials. When we make an allowance of about ⅙th of the diameter for wear, then for cast-iron $c = 960$, and for malleable iron $c = 1080$. Substituting these, we obtain,

For cast-iron,

$$d = D\left\{\frac{\cdot7854 \times m \times P}{960 \times n}\right\}^{\frac{1}{3}} = D\left\{\frac{m \times P}{1222 \times n}\right\}^{\frac{1}{3}}.$$

For malleable iron,

$$d = D\left\{\frac{\cdot7854 \times m \times P}{1080 \times n}\right\}^{\frac{1}{3}} = D\left\{\frac{m \times P}{1376 \times n}\right\}^{\frac{1}{3}}.$$

These may be expressed in the following rule.

Rule. — *To find the diameter of a revolving shaft. — Form a reserved divisor thus: multiply the number of revolutions which the shaft makes for each double stroke of the piston by the number* 1222 *for cast iron, and the number* 1376 *for malleable iron. Then divide the radius of the crank, or the radius of the wheel, by the diameter of the cylinder; multiply the quotient by the greatest pressure of the steam in the boiler expressed in lbs. per square inch; divide the product by the reserved divisor; extract the cube root of the quotient, and multiply the result by the diameter of the cylinder in inches. The product is the diameter of the shaft in inches.*

STRENGTH OF RODS WHEN THE STRAIN IS WHOLLY TENSILE; SUCH AS THE PISTON ROD OF SINGLE ACTING ENGINES, PUMP RODS, ETC.

In treating of the resistance which a beam offers to a force tending to draw it in the direction of its length, we observed that it was proved, both from theory and experiment, that this resistance was proportional to the area of the transverse section. Denoting the diameter of the rod in inches by d, the force of cohesion of a bar of one square inch in section of the material by f; the resistance of the rod is $\frac{\pi}{4}\ f\,d^2 = \cdot7854 \times f\,d^2$. We have the equation $\frac{\pi}{4}\ P\ D^2 = \frac{\pi}{4}\ f\ d^2$; from which we find $d = D\sqrt{\frac{P}{f}}$. For malleable iron $f = 17{,}800$ lbs.; but it ought to be remembered that this value is only the mean or average value of several experiments, so that for certain qualities of metal it ought to be less. Hence we ought to make an allowance for the probability that the iron is of an inferior quality. Again, the formula is determined upon the supposition that the force is applied directly to the axis of the rod. When the force is applied at some other point, the rod is liable to be bent; so that, in order to preserve the rod from flexure, it is necessary to make it stronger than would be necessary if the force were applied to the axis. It has been assumed that, in every case in which the force is wholly tensile, there is a possibility of the strain deviating one sixth of the diameter of the rod from the axis, and as an allowance for both of these casualties we may take $f = 9025$; with this our formula becomes

$$d = \frac{D}{95}\sqrt{P}.$$

This formula, when expressed in words, gives the following rule.

To find the diameter of a rod exposed to a tensile force only.

Rule.—*Multiply the diameter of the piston in inches by the square root of the greatest elastic force of the steam in the boiler estimated in lbs. per square inch; the product, divided by 95, is the diameter of the rod in inches.*

Example.—Required the diameter of the transverse section of a piston rod in a single acting engine, when the diameter of the cylinder is 50 inches, and the greatest possible force of the steam in the boiler is 16 lbs. per square inch. Here, according to the formula,

$$d = \frac{50}{95}\sqrt{16} = \frac{200}{95} = 2{\cdot}1 \text{ in.}$$

OF THE STRENGTH OF RODS ALTERNATELY EXTENDED AND COMPRESSED, SUCH AS THE PISTON RODS OF DOUBLE-ACTING ENGINES.

The theory of the resistance which columns whose lengths do not greatly exceed their breadths offer to forces tending to crush them is still in a very imperfect state. When the length exceeds the breadth, then the column bends to one side before breaking, so that the crushing force partakes of the nature of a transverse force. The force increases with the flexure; hence it has been laid down as a general rule, by writers on the strength of materials, never to load a long column by a force exceeding that which it can bear when applied as a tensile force. Thus, if the column be cylindrical, and its length greatly exceed its diameter d, then the greatest weight which should be placed upon the column is $\cdot 7854 \times f \times d^2$. This is the maximum load, when it is applied so as to act in the axis of the cylindrical rod; but when the load is applied at a point different from the axis, its efficacy is very much increased. Now, in the case of the rods used in a steam engine there is always a possibility of the force deviating nearly one half the diameter from the axis, so that we must make a provision for this. It may be shown, from theoretical considerations, that a cylindrical rod whose diameter is d may always be safely loaded by a weight $= \frac{1}{9} f d^2$. Assuming this, we have to determine d, the equation

$$\cdot 7854 \times P \times D^2 = \tfrac{1}{9} f \times d^2;$$

$$\text{therefore } d = D\sqrt{\frac{7{\cdot}0686}{f}P}.$$

By substituting the corresponding values of f, we have

$$\text{for cast iron} \qquad d = \frac{D}{47}\sqrt{P}.$$

$$\text{for malleable iron } d = \frac{D}{50}\sqrt{P}.$$

These formulas give the following rule:—

Rule.—*Multiply the diameter of the piston in inches by the square root of the maximum pressure of the steam in lbs. per square inch; divide the product by*

47 for cast iron,
50 for malleable iron.

This rule applies to the piston rods of double-acting engines, parallel-motion rods, air-pump and force-pump rods, and the like. The rule may also be applied to determine the strength of connecting rods, by taking, instead of P, a number P′, such that P′ × sine of the greatest angle which the connecting rod makes with the direction = P.

Example.—Supposing the greatest force of the steam in the boiler to be 16 lbs. per square inch, and the diameter of the cylinder 50 inches; required the diameter of the piston rod, supposing the engine to be double acting.

In this case

$$\text{for cast iron } d = \frac{D}{47}\sqrt{P} = \frac{50 \times 4}{47} = 5 \text{ inches nearly.}$$

$$\text{for malleable iron } d = \frac{D}{50}\sqrt{P} = 4 \text{ inches.}$$

The pressure, however, is always taken in practice at more than 16 lbs. If the pressure be taken at 25 lbs., the diameter of a malleable iron piston rod will be 5 inches, which is the usual proportion. Piston rods are never made of cast iron, but air-pump rods are sometimes made of brass, and the connecting rods of land engines are cast iron in most cases.

Formulae for the Strength of various Parts of Marine Engines.—The investigations we have given will serve to show the manner in which the strengths proper for various parts of engines may be derived. It would produce a needless diffuseness to pursue these investigations into all the cases for which a solution is required, and we shall, therefore, give a series of formulae, derived in the manner we have illustrated, of the dimensions proper for the parts of marine engines, and shall recapitulate, with all possible brevity, the data upon which the determinations rest.

Let pressure of the steam in boiler $= p$ lbs. per square inch,
Diameter of cylinder $=$ D inches,
Length of stroke $= 2$ R inches.

The vacuum below the piston is never complete, so that there always remains a vapour of steam possessing a certain elasticity. We may suppose this vapour to be able to balance the weight of the piston. Hence the entire pressure on the square inch of piston in lbs. $= p +$ pressure of atmosphere $= 15 + p$. We shall substitute P for $15 + p$. Hence

$$\text{Entire pressure on piston in lbs.} = \cdot 7854 \times (15 + p) \times D^2$$
$$= \cdot 7854 \times P \times D^2.$$

The dimensions of the paddle-shaft journal may be found from the following formula, which are calculated so that the strain in ordinary working $= \frac{1}{3}$ elastic force.

$$\text{Diameter of paddle-shaft journal} = \cdot 08264 \left\{R \times P \times D^2\right\}^{\frac{1}{3}}$$

$$\text{Length of ditto} = 1\tfrac{1}{4} \times \text{diameter.}$$

The dimensions of the several parts of the crank may be found from the following formulas, which are calculated so that the strain in ordinary working = one half the elastic force; and when one paddle is suddenly brought up, the strain at shaft end of crank $= \frac{2}{3}$ elastic force, the strain at pin end of crank = elastic force.

Exterior diameter of large eye = diameter of paddle shaft +

$$\left\{\frac{D\left[P \times 1{\cdot}561 \times R^2 + \cdot 00494 \times D^2 \times P^2\right]^{\frac{1}{2}}}{75{\cdot}59 \times \sqrt{R}}\right\}^{\frac{2}{3}}$$

Length of ditto = diameter of paddle shaft.
Exterior diameter of small eye = diameter of crank pin + $\cdot 02521 \times \sqrt{P} \times D$.
Length of ditto $= \cdot 0375 \times \sqrt{P} \times D$.
Thickness of web at paddle centre =

$$\left\{\frac{D^2 \times P \times \sqrt{\left\{1{\cdot}561 \times R^2 + \cdot 00494 \times D^2 \times P\right\}}}{9000}\right\}^{\frac{1}{3}}$$

Breadth of ditto = 2 × thickness.
Thickness of web at pin centre $- \cdot 022 \times \sqrt{P} \times D$.
Breadth of ditto $= \frac{3}{2} \times$ thickness.

As these formulas are rather complicated, we may show what they become when $p = 10$ or $P = 25$.

Exterior diameter of large eye = diameter of paddle shaft +

$$\left\{\frac{D\sqrt{(1{\cdot}561 \times R^2 + \cdot 1235 \times D^2)}}{15{\cdot}12 \times \sqrt{R}}\right\}^{\frac{2}{3}}$$

Length of ditto = diameter of paddle shaft.
Exterior diameter of small eye = diameter of crank pin + $\cdot 126 \times D$.
Length of ditto $= \cdot 1875 \times D$.
Thickness of web at pin centre $= \cdot 11 \times D$.
Breadth of ditto $= \frac{3}{2} \times$ thickness of web.

The dimensions of the crank-pin journal may be found from the following formulas, which are calculated so that strain when bearing at outer end = elastic force, and in ordinary working strain = one third of elastic force.

Diameter of crank-pin journal $= \cdot 02836 \times \sqrt{P} \times D$.
Length of ditto $= \frac{7}{8} \times$ diameter.

The dimensions of the several parts of the cross head may be found from the following formulas, in which we have assumed, for the purpose of calculation, the length $= 1{\cdot}4 \times D$. The formulas have been calculated so as to give the strain of web $= \frac{1}{2{\cdot}225} \times$ elastic force; strain of journal in ordinary working $= \frac{1}{2{\cdot}33} \times$ elastic force, and when bearing at outer end $= \frac{1}{1{\cdot}165} \times$ elastic force.

Exterior diameter of eye = diameter of hole + $\cdot 02827 \times P^{\frac{1}{2}} \times D$.

Depth of ditto $= \cdot 0979 \times P^{\frac{1}{3}} \times D$.
Diameter of journal $= \cdot 01716 \times \sqrt{P} \times D$.
Length of ditto $= \frac{7}{8}$ diameter of journal.

Thickness of web at middle $= \cdot 0245 \times P^{\frac{1}{3}} \times D$.

Breadth of ditto $= \cdot 09178 \times P^{\frac{1}{3}} \times D$.

Thickness of web at journal $= \cdot 0122 \times P^{\frac{1}{2}} \times D$.

Breadth of ditto $= \cdot 0203 \times P^{\frac{1}{2}} \times D$.

The dimensions of the several parts of the piston rod may be found from the following formulas, which are calculated so that the strain of piston rod $= \frac{1}{9}$ elastic force.

$$\text{Diameter of piston rod} = \frac{\sqrt{P} \times D}{50}$$

Length of part in piston $= \cdot 04 \times D \times P$

Major diameter of part in crosshead $= \cdot 019 \times \sqrt{P} \times D$.
Minor diameter of ditto $= \cdot 018 \times \sqrt{P} \times D$.
Major diameter of part in piston $= \cdot 028 \times \sqrt{P} \times D$.
Minor diameter of ditto $= \cdot 023 \times \sqrt{P} \times D$.

Depth of gibs and cutter through crosshead $= \cdot 0358 \times P^{\frac{1}{2}} \times D$.

Thickness of ditto $= \cdot 007 \times P^{\frac{1}{2}} \times D$.
Depth of cutter through piston $= \cdot 017 \times \sqrt{P} \times D$.

Thickness of ditto $= \cdot 007 \times P^{\frac{1}{2}} \times D$.

The dimensions of the several parts of the connecting rod may be found from the following formulas, which are calculated so that the strain of the connecting rod and the strain of the strap are both equal to one-sixth of the elastic force.

Diameter of connecting rod at ends $= \cdot 019 \times P^{\frac{1}{2}} \times D$.

Diameter of ditto at middle $= \{1 + \cdot 0035 \times \text{length in inches}\} \times \cdot 019 \times \sqrt{P} \times D$.

Major diameter of part in crosstail $= 0196 \times P^{\frac{1}{2}} \times D$.

Minor ditto $= 018 \times P^{\frac{1}{2}} \times D$.

Breadth of butt $= \cdot 0313 \times P^{\frac{1}{2}} \times D$.

Thickness of ditto $= \cdot 025 \times P^{\frac{1}{2}} \times D$.

Mean thickness of strap at cutter $= \cdot 00854 \times \sqrt{P} \times D$.

Ditto above cutter $= \cdot 00634 \times \sqrt{P} \times D$.

Distance of cutter from end of strap $= \cdot 0097 \times \sqrt{P} \times D$.

Breadth of gibs and cutter through crosstail $= \cdot 0358 \times P^{\frac{1}{2}} \times D$.

Breadth of gibs and cutter through butt $= \cdot 022 \times P^{\frac{1}{2}} \times D$.

Thickness of ditto $= \cdot 00564 \times P^{\frac{1}{2}} \times D$.

The dimensions of the several parts of the side rods may be found from the following formulas, which are calculated so as to make the strain of side rod = one-sixth of elastic force, and the strains of strap and cutter = one-fifth of elastic force.

Diameter of cylinder side rods at ends $= \cdot 0129 \times P^{\frac{1}{2}} \times D$.

Diameter of ditto at middle $= (1 + \cdot 0035 \times \text{length in inches})$.

$$\times \cdot 0129 \times P^{\frac{1}{2}} \times D.$$

Breadth of butt $= \cdot 0154 \times P^{\frac{1}{2}} \times D$.

Thickness of ditto $= \cdot 0122 \times P^{\frac{1}{2}} \times D$.

Diameter of journal at top end of side rod $= 01716 \times P^{\frac{1}{2}} \times D$.

Length of journal at top end $= \frac{5}{8}$ diameter.

Diameter of journal at bottom end $= \cdot 014 \times P^{\frac{1}{2}} \times D$.

Length of ditto $= \cdot 0152 \times P^{\frac{1}{2}} \times D$.

Mean thickness of strap at cutter $= \cdot 00643 \times P^{\frac{1}{2}} \times D$.

Ditto below cutter $= \cdot 0047 \times P^{\frac{1}{2}} \times D$.

Breadth of gibs and cutter $= \cdot 016 \times P^{\frac{1}{2}} \times D$.

Thickness of ditto $= \cdot 0033 \times P^{\frac{1}{2}} \times D$.

The dimensions of the main centre journal may be found from the following formulas, which are calculated so as to make the strain in ordinary working = one half elastic force.

Diameter of main centre journal $= \cdot 0367 \times P^{3} \times D$.
Length of ditto $= \frac{3}{4} \times$ diameter.
The dimensions of the several parts of the air-pump may be found from the corresponding formulas given above, by taking for D another number *d* the diameter of air-pump.

DIMENSIONS OF THE SEVERAL PARTS OF FURNACES AND BOILERS.

Perhaps in none of the parts of a steam-engine does the practice of engineers vary more than in those connected with furnaces and boilers. There are, no doubt, certain proportions for these, as well as for the others, which produce the maximum amount of useful effect for particular given purposes; but the determination of these proportions, from theoretical considerations, has hitherto been attended with insuperable difficulties, arising principally from our imperfect knowledge of the laws of combustion of fuel, and of the laws according to which caloric is imparted to the water in the boiler. In giving, therefore, the following proportions for the different parts, we desire to have it understood that we do not affirm them to be the best, absolutely considered; we give them only as the average practice of the best modern constructors. In most of the cases we have given the average value per nominal horse power. It is well known that the term a horse power is a conventional unit for measuring the size of steam engines, ust as a foot or a mile is a unit for the measurement of extension. There is this difference, however, in the two cases, that whereas the length of a foot is fixed definitively, and is known to every one, the dimensions proper to an engine horse power differ in the practice of every different maker; and the same kind of confusion is thereby introduced into engineering as if one person were to make his foot-rule eleven inches long, and another thirteen inches. It signifies very little what a horse power is defined to be; but when once defined the measurement should be kept inviolable. The question now arises, what standard ought to be the accepted one. We think that scarcely any one will doubt that the standard fixed by Boulton and Watt is entitled to the preference, since it answers all the purposes of a standard as well as any other, and since they were the first to introduce the plan of measuring engines by horses' power. We have given a very extensive table of the nominal horse power of steam engines approximating to their standard in pages 96 and 97 of this work. For our present purpose, however, it is necessary to connect by a formula the three quantities, nominal horses' power, length of stroke, and diameter of cylinder. With this intention

Let S = length of stroke in feet,
d = diameter of cylinder in inches;

then it may be shown that, by adopting the standard of Boulton and Watt, as established by the late Mr. Watt,

$$\text{nominal horse power} = \frac{d^2 \times \sqrt[3]{S}}{47} \text{ nearly.}$$

We proceed now to state what seems (judging by the practice of the best makers) to be the best proportions for the different parts of the furnace and boiler.

I. *Area of Fire Grate.*

The average practice is to give ·55 square feet for each nominal horse power. Hence the following rule.

RULE 1. — *To find the area of the fire grate.—Multiply the number of horses' power by ·55; the product is the area of the fire grate in square feet.*

Example.—Required the total area of the fire grate for an engine of 400 horse power. Here total area of fire grate in square feet $= 400 \times \cdot 55 = 220$.

A rule may also be found for expressing the area of the fire grate in terms of the length of stroke and the diameter of the cylinder. For this purpose we have,

$$\text{total area of fire grate} = \frac{\cdot 55 \times d^2 \times \sqrt[3]{S}}{47} \text{ feet} = \frac{d^2 \times \sqrt[3]{S}}{86} \text{ feet.}$$

This formula expressed in words gives the following rule.

RULE 2.—*To find the area of fire grate.—Multiply the cube root of the length of stroke in feet by the square of the diameter in inches; divide the product by 86: the quotient is the area of fire grate in square feet.*

Example.—Required the total area of the fire grate for an engine whose stroke = 8 feet. and diameter of cylinder = 50 inches.

Here, according to the rule,

$$\text{total area of fire grate in square feet} = \frac{50^2 \times \sqrt[3]{8}}{86} = \frac{2500 \times 2}{86} = \frac{5000}{86} =$$

59 nearly.

In order to work this example by the first rule, we find from the table, page 96, that the nominal horses' power of the engine whose dimensions we have specified is 104·3; hence,

$$\text{total area of fire grate in square feet} = 106 \cdot 4 \times \cdot 55 = 58 \cdot 5.$$

With regard to these rules we may remark, not only that they are founded on practice, and therefore empyrical. but they are only applicable to large engines. When an engine is very small, it requires a much larger area of fire grate in proportion to its size than a larger one. This depends upon the necessity of having a certain amount of fire grate for the proper combustion of the coal.

II. *Length of Furnace.*

The length of the furnace differs considerably, even in the practice of the same engineer. Indeed all the dimensions of the furnace depend to a certain extent upon the peculiarity of its position. From the difficulty of firing long furnaces efficiently, it has been found more beneficial to restrict the length of the furnace to about six feet than to employ furnaces of greater length.

III. *Height of Furnace above Bars.*

This dimension is variable, but it is a common practice to make the height about two feet.

IV. *Capacity of Furnace Chamber above Bars.*

In order to determine the average capacity of furnace chambers above bars, we may here specify some particular engines.

Vessel.	Horse Power.	Total Capacity above Bars.	Capacity per H.P.
Thames and Medway	434	540	1·2
Sydenham - -	78	84·5	1·08
Retribution - -	903	704	·78
Royal Consort -	317	537·3	·8
Her Majesty - -	317	537·3	·8
Forth - - - -	430	513·8	1·2
Dee and Solway -	434	494	1·1
Achilles - - -	446·8	583·2	1·3
Queen - - -	175	117·8	·67

The average value of these, per horse power, may be taken at 1·17 feet. Hence the following rule: —

Rule. — *To find the capacity of furnace chamber above bars. Multiply the number of nominal horses' power by* 1·17; *the product is the capacity of furnace chambers above bars in cubic feet.*

V. *Areas of Flues or Tubes in smallest Part.*

We may here specify the dimensions of the flues or tubes of the boilers of several steam vessels.

Vessel.	Collective Power of Engines.	Area of minimum Section of Flues or Tubes.	Area per H.P.
Sydenham	78	7·25 ft.	13·3 in.
Royal Consort	317	26·4	11·9
Her Majesty	317	26·4	11·9
Forth	430	28·8	9·6
Dee and Solway	434	29·2	9·4

The average value of the area per horse power is 11·2 sq. in. Hence we have the following rule: —

Rule. — *To find the total area of the flues or tubes in smallest part. — Multiply the number of horse power by* 11·2; *the product is the total area in square inches of flues or tubes in smallest part.*

Example. — Required total area of flues or tubes for the boiler of a steam engine when the horse power = 400.

For this example we have according to the rule,

Total area in square inches = 400 × 11·2 = 4480.

We may also find a very convenient rule expressed in terms of the stroke and the diameter of cylinder. Thus,

$$\text{Total area of tubes or flues in square inches} = \frac{11{\cdot}2 \times d^2 \times \sqrt[3]{S}}{47} = \frac{d^2 \times \sqrt[3]{S}}{4}$$

VI. *Effective heating Surface.*

In order to find the average quantity of heating surface per horse power, we shall here specify the total amount of heating surface of different vessels whose engines have different horses' power. The effective heating surface of flue boilers is the whole of furnace surface above bars, the whole of tops of flues, half the sides of flues, and none of the bottoms; hence the effective flue surface is about half the total flue surface. In tubular boilers, however, the whole of the tube surface is reckoned effective surface.

EFFECTIVE HEATING SURFACE OF FLUE BOILERS.

Vessels.	Horse Power.	Total effective heating Surface.	Effective heating Surface per Horse Power.
Forth - - -	430	2895·7	6·7
Dee and Solway -	434	2512	5·78
Thames and Medway	434	2111·5	4·86
Retribution - -	903	3537·56	3·8
Achilles - -	446·8	2703·6	6·05

The mean of these numbers is 5·4, but for the larger class of boilers we may take less than this, and 5 square feet per horse power answers very well.

Rule 1. — *To find the effective heating surface of marine flue boilers of large size. — Multiply the number of nominal horses' power by* 5; *the product is the area of effective heating surface in square feet.*

Example. — Required the effective heating surface of an engine of 400 nominal horse power.

In this case, according to the rule, Effective heating surface in square feet = 400 × 5 = 2000.

The effective heating surface may be expressed in terms of the length of stroke and the diameter of the cylinder, as follows: —

$$\text{Effective heating surface in square feet} = \frac{5 \times d^2 \times \sqrt[3]{S}}{47} = \frac{d^2 \times \sqrt[3]{S}}{10} \text{ nearly.}$$

The formula, expressed in words, gives the following rule: —

Rule 2. — *To find the total effective heating surface of marine flue boilers. — Multiply the square of the diameter of cylinder in inches by the cube root of the length of stroke in feet; divide the product by* 10: *the quotient expresses the number of square feet of effective heating surface.*

Example. — Required the amount of effective heating surface for an engine whose stroke = 8 ft., and diameter of cylinder = 50 inches.

Here, according to Rule 2., Effective heating surface in square feet =

$$\frac{50^2 \times \sqrt[3]{8}}{10} = \frac{2500 \times 2}{10} = \frac{5000}{10} = 500.$$

To solve this example according to the first rule, we have, referring to table, pages 96. and 97., the nominal horse power of the engine equal to 106·4. Hence, according to Rule 2., Total effective heating surface in square feet = 106·4 × 4·92 = 523½.

EFFECTIVE HEATING SURFACE OF TUBULAR BOILERS.

The effective heating surface of tubular boilers is about equal to the total heating surface of flue boilers, or is double the effective surface, as appears by the following table; but then the total tube surface is reckoned effective surface.

Vessels.	Horse Power.	Total effective heating Surface.	Effective heating Surface per Horse Power.
Her Majesty, and Royal Consort -	317	3344	10·5
Queen - - -	175	1995	11·4
Braganza - -	289	3463	11·98
Ocean - - -	232	3128	13·48

The more important particulars, however, of tubular boilers are more clearly exhibited by the following table: —

TABLE OF DIMENSIONS OF TUBULAR BOILERS.

Power - - -	270 H. P.	288 H. P.	252 H. P.	293 H. P.
Name of Vessel - -	Royal George	Braganza	Dundee	Tagus
Diameter of Cylinder -	61 in.	62 in.	58 in.	62 in.
Length of Stroke - -	5 ft.	5 ft. 6 in.	5 ft. 6 in.	5 ft. 9 in.
Boilers made by - -	Tod & M'Gregor	Bury, Curtis and Co.	Hutton & Steel	Miller and Ravenhill
How supplied with Steam -	Fair	Abundance	Too much	Short
Furnace Bar per H. P. -	.533 ft.	.339 ft.	.761 ft.	.382 ft.
Length of Tube per H. P. -	10.44 ft.	13.96 ft.	14.56 ft.	9 ft.
Sectional area of Tube per H. P. in Square Inches -	11.36 in.	14.44 in.	19.5 in.	8.40 in.
Heating Surface of Tube per H. P. - - -	8.20 ft.	10.98 ft.	11.383 ft.	6.35 ft.
Area of Fire-grate per Square Foot of sectional area of Tubes - -	6.76	3.75	5.62	6.6
Power - - -	317 H. P.	160 H. P.	82 H. P.	260 H. P.
Name of Vessel - -	Royal Consort	The Queen Whitehaven St. Nav. Compy.	Invincible	Phœnix Government Steamer
Diameter of Cylinder -	65		49	
Length of Stroke - -	5 ft. 6 in.		4 ft. 2 in.	
Boilers made by - -	Tod and M'Gregor	Fawcett and Preston	Tod and M'Gregor	Penn & Co.
How supplied with Steam -	Abundance	Not known	Abundance	Scarce
Furnace Bar per H. P. -	.564 ft.	.367 ft.	.888 ft.	.430 ft.
Length of Tube per H. P. -	12.48 ft.	11.277 ft.	12 68 ft.	13 ft.
Sectional area of Tube per H. P. in Square Inches -	14.13 in.	11 in.	11.56 in.	14 in.
Heating Surface of Tube per H. P. - - -	9.762 ft.	8.65 ft.	9.12 ft.	10.2 ft.
Area of Fire-grate per Square Foot of sectional area of Tubes - -	5.747	4.8	11.05	4.42

It appears from these data that the total heating surface of flue and tubular marine boilers is about the same, namely, about 10 square feet per horse power.

VII. *Area of Chimney.*

For the purpose of deducing a rule for this we shall here specify some particular examples.

Vessel.	Collective Power of Engines.	Area of Chimney.	Area per H.P.
Sydenham	78	5·94 sq. ft.	10·96 sq. in.
Royal Consort	317	23·75	10·79
Her Majesty	317	23·75	10·79
Forth	430	24·5	8·20
Dee and Solway	434	28·3	9·39
Queen	160	12·5	11·25

The mean value of the quantities in the last column is 10·23. Hence we have the following rule :—

Rule 1.— *To find the area of chimney.—Multiply the number of nominal horse power by* 10·23*; the product is the area of chimney in square inches.*

Example.— Required the area of the chimney for an engine of 400 nominal horse power.

In this example we have, according to the rule,

$$\text{area of chimney in square inches} = 400 \times 10{\cdot}23 = 4092.$$

We may also find a formula for connecting together the area of the chimney, the length of the stroke, and the diameter of the cylinder; thus

$$\text{area of chimney in square inches} = \frac{10{\cdot}23 \times d^2 \times \sqrt[3]{S}}{47} = \frac{d^2 \times \sqrt[3]{S}}{5}.$$

This formula, expressed in words, gives the following rule : —

Rule 2.— *To find the area of the chimney.—Multiply the square of the diameter expressed in inches by the cube root of the stroke expressed in feet; divide the product by the number* 5*; the quotient expresses the number of square inches in the area of chimney.*

Example.— Required the area of the chimney for an engine whose stroke = 8 feet, and diameter of cylinder = 50 inches.

We have in this example from the rule,

$$\text{area of chimney in square inches} = \frac{50^2 \times \sqrt[3]{8}}{5} = \frac{2500 \times 2}{5} = 1000.$$

To work this example according to the first rule, we find, by referring to the table, pages 96. and 97., that the nominal horse power of this engine is 104·6 : hence, according to Rule 1.,

$$\text{area of chimney in square inches} = 104{\cdot}6 \times 10{\cdot}23 = 1070.$$

The latter value is greater than the former one by 70 inches. This difference arises from our taking too great a divisor in Rule 2. Either of the values, however, are near enough for all practical purposes.

VIII. *Water in Boiler.*

The quantity of water in the boiler differs not only for different boilers, but differs even for the same boiler at different times. It may be useful, however, to know the average quantity of water in the boiler for an engine of a given horse power. Following out the same plan that we have followed with the others, we here subjoin some particular examples of particular engines.

Vessel.	Collective Power of Engines.	Average Quantity of Water in the Boiler.	Average Quantity per H.P.
Achilles - -	446·8	2900	6·49
Sydenham - -	78	291·5	3·74
Retribution - -	903	4056	4·4
Her Majesty and Royal Consort -	317	1433·3	4·5
Forth - - -	430	2439·2	5·7
Dee and Solway -	434	2338·4	5·4
Thames and Medway	434	2647	6·09

The mean value of the last column is about 5 : hence we may say that on an average there is 5 cubic feet of water in the boiler for each nominal horse power of the engine. We may therefore form the following rule :

Rule 1.— *To determine the average quantity of water in the boiler.—Multiply the number of horses' power by* 5*; the product expresses the cubic feet of water usually in the boiler.*

This rule may be so modified as to make it depend upon the stroke and diameter of the cylinder of engine ; thus,

$$\text{cubic feet of water in the boiler} = 5 \times \text{nominal horse power} = \frac{5 \times d^2 \times \sqrt[3]{S}}{47}$$

This formula, when expressed in words, gives the following rule :

Rule 2. *To determine the cubic feet of water usually in the boiler.—Multiply together the cube root of the stroke in feet, the square of the diameter of the cylinder in inches, and the number* 5*; divide the continual product by* 47*; the quotient expresses the cubic feet of water usually in the boiler.*

Example.— Required the usual quantity of water in the boilers of an engine whose stroke = 8 ft., and diameter of cylinder = 50 in.

Here we have from the rule,

$$\text{cubic feet of water in boiler} = \frac{5 \times 50^2 \times \sqrt[3]{8}}{47} = \frac{5 \times 2500 \times 2}{47} = \frac{25000}{47} = 532$$
nearly.

In order to work this example by Rule 1, it is necessary to refer to the table, pages 96 and 97. According to the table, the engine, with the dimensions we have specified, is of 106·4 nominal horse-power. Hence, according to Rule 1,

$$\text{cubic feet of water in boiler} = 106{\cdot}4 \times 5 = 532.$$

IX. *Area of Water Level.*

We here subjoin some examples of the area of water level in the boilers of particular steam vessels.

Vessel.	Collective Power of Engines.	Area of Water Level.	Area per H. P.
Dee and Solway -	434	695·4	1·6
Sydenham - -	78	65·25	·84
Retribution - -	903	850·5	·94
Her Majesty and Royal Consort -	317	304·6	·96
Forth - - -	430	564·4	1·31
Thames and Medway	434	413	·98
Achilles - - -	446·8	565	1·3

The mean value of the numbers in the last column is a little more than 1. Hence we may take one square foot of water level for each horse power. We may put this result in the form of a rule.

Rule 1. — *To find the area of water level. — The area of water level contains the same number of square feet as there are units in the number expressing the nominal horse power of the engine.*

Example.—Required the area of water level for an engine of 200 nominal horse power. According to the rule, the answer is 200 square feet.

To proceed in the same manner as we have done with the others, we add a rule for finding the area of water level when the diameter of cylinder and the length of stroke is given.

Rule 2.— *To find the area of water level.—Multiply the square of the diameter in inches by the cube root of the stroke in feet; divide the product by* 47*; the quotient expresses the number of square feet in the area of water level.*

Example.—Required the area of the water level for an engine whose stroke is 8 feet, and diameter of cylinder 50 inches.

In this case, according to the rule,

$$\text{area of water level in square feet} = \frac{50^2 \times \sqrt[3]{8}}{47} = 106$$

In order to work this example by Rule 1., we must refer to the table of nominal horse power at pages 96 and 97; and we find that the nominal horse power is 106·4. Hence, according to the rule, the area of water level = 106·4 square feet.

X. *Steam Room.*

It is obvious that the steam room, like the quantity of water, is an extremely variable quantity, differing, not only for different boilers, but even in the same boiler at different times. It is desirable, however, to know the content of that part of the boiler usually filled with steam. Following the same method as previously, we here add some examples of the average quantity of steam room in the boilers of different steam vessels.

Vessel.	Collective Power of Engines.	Total Steam Room.	Steam Room per H. P.
Achilles - -	446·8	1380	3
Sydenham - -	78	215	2·8
Retribution - -	903	2272·4	2·5
Her Majesty and Royal Consort -	317	850	2·68
Forth - - -	430	1880	4·4
Dee and Solway -	434	1770	4·1
Thames and Medway	484	1064	2·45

The mean value of the quantities in the last column is about 3 : hence we have the following rule for determining the average quantity of steam room.

Rule 1.— *To determine the average quantity of steam room.—Multiply the number expressing the nominal horse power by* 3*; the product expresses the average number of cubic feet of steam room.*

Example.—Required the average capacity of steam room for an engine of 460 nominal horse power.

According to the rule,

Average capacity of steam room = 460 × 3 cubic feet = 1380 cubic feet.

This rule may be so modified as to apply when the length of stroke and diameter of cylinder is given; thus,

$$\text{cubic feet of steam room} = \frac{3 \times d^2 \times \sqrt[3]{S}}{47} = \frac{d^2 \times \sqrt[3]{S}}{15} \text{ nearly.}$$

This formula, when expressed in words, gives the following rule : —

Rule 2.—*Multiply the square of the diameter of the cylinder in inches by the cube root of the stroke in feet; divide the product by* 15*; the quotient expresses the number of cubic feet of steam room.*

Example.—Required the average capacity of steam room for an engine whose stroke is 8 feet, and diameter of cylinder 5 inches.

In this case, according to the rule,

$$\text{Steam room in cubic feet} = \frac{50^2 \times \sqrt[3]{8}}{15} = \frac{2500 \times 2}{15} = \frac{5000}{15} = 333\tfrac{1}{3}.$$

In order to work this example by the first rule, we must refer to the table of nominal horse-power. We find that the nominal horse power of this engine is 106·4; hence, according to Rule 1.,

$$\text{average stream room in cubic feet} = 106{\cdot}4 \times 3 = 320 \text{ nearly.}$$

Before leaving these rules, we would again repeat that they ought not to be considered as rules founded upon considerations for giving the maximum effect from the combustion of a given amount of fuel; and consequently the engineer ought not to consider them as invariable, but merely to be followed as far as circumstances will permit. We give them, indeed, as the medium value of the very variable practice of several well-known constructors; consequently, although the proportions given by the rules may not be the best possible for producing the most useful effect, still the engineer who is guided by them is sure not to be very far from the common practice of most of our best engineers. It has often been lamented that the methods used by different engine makers for estimating the nominal powers of their engines has been so various that we can form no real estimate of the dimensions of the engine, from its reputed nominal horse power, unless we know its maker; but the same confusion exists, also, to some extent, in the construction of boilers. Indeed many things may be mentioned, which have hitherto operated as a barrier to the practical application of any standard of engine power for proportioning the different parts of the boiler and furnace. The magnitude of furnace and the extent of heating surface necessary to produce any required rate of evaporation in the boiler are indeed known, yet each engine maker has his own rule in these matters, and which he seems to think preferable to all others, and there are various circumstances influencing the result which render facts incomparable unless those circumstances are the same. Thus the circumstances that govern the rate of evaporation, as influenced by different degrees of draught, may be regarded as but imperfectly known. And, supposing the difficulty of ascertaining this rate of evaporation were surmounted, there would still remain some difficulty in ascertaining the amount of power absorbed by the condensation of the steam on its passage to the cylinder—the imperfect condensation of the same steam after it has worked the piston—the friction of the various moving parts of the machinery—and, especially, the difference of effect of these losses of power in engines constructed on different scales of magnitude. Practice must often vary, to a certain extent, in the construction of the different parts of the boiler and furnace of an engine; for, independently of the difficulty of solving the general problem in engineering, the determination of the maximum effect with the minimum of means, practice would still require to vary according as in any particular case the desired minimum of means was that of weight, or bulk, or expense of material. Again in estimating the proper proportions for a boiler and its appendages, reference ought to be made to the distinction between the "power" or "effect" of the boiler, and its "duty." This is a distinction to be considered also in the engine itself. The power of an engine has reference to the time it takes to produce a certain mechanical effect without reference to the amount of fuel consumed; and, on the other hand, the duty of an engine has reference to the amount of mechanical effect produced by a certain consumption of fuel, and is independent of the time it takes to produce that effect. In expressing the duty of engines, it would have prevented much needless confusion if the duty of the boiler had been entirely separated from that of the engine, as, indeed, they are two very distinct things. The duty performed by ordinary land rotative steam engines is—

One horse power exerted by 10 lbs. of fuel an hour; or,
Quarter of a million of lbs. raised one foot high by 1 lb. of coal; or,
Twenty millions of lbs. raised one foot by each bushel of coals.

Though in the best class of rotative engines the consumption is not above half of this amount.

The constant aim of different engine makers is to increase the amount of the duty; that is, to make 10 lbs. of fuel exert a greater effect than one horse power; or, in other words, to make 1 lb. of coal raise more than a quarter of a million of lbs. one foot high. To a great extent they have been successful in this. They have caused 5 lbs. of coal to exert the force of one horse power, and even in some cases as little as 3½ lbs.; but in these latter cases the economy is due chiefly to expansive action. In some of the engines, however, working with a consumption of 10 lbs. of coal per nominal horse power per hour, the power really exerted amounts to much more than that represented by 33,000 lbs. lifted one foot high in the minute for each horse power. Some engines lift 56,000 lbs. one foot high in the minute by each horse power, with a consumption of 10 lbs. of coal per horse power per hour; and even this performance has been somewhat exceeded without a recourse to expansive action. In all modern engines the actual performance much exceeds the nominal power; and reference must be had to this circumstance in contrasting the duty of different engines.

We may here give the following table, taken from the experiments or collected data of Parkes, Wicksteed, and Boulton and Watt, and which is supposed to contrast the respective distinguishing features, and the comparative economy, of the two systems of generating steam practised in the Boulton and Watt boiler, and the Trevithick or Cornish boiler.

	No.	Number of Boilers.	Localities.	Per square Foot of Fire-grate.	Per lb. of Water evaporated per Hour.	Per lb. of Fuel consumed per Hour.	Fuel burned per Square Foot of Grate per Hour.	Water evaporated from initial Temperature of 90° by each lb. of Coal.
Boulton and Watt boiler, 16 to 18 feet long, weighing 7½ tons.	1 2 3	1 1 1	Old Ford Albion Mill Mean of 8	21·28 15·78 13·88	0·15 0·163 0·171	1·294 1·300 1·315	16·44 12·21 10·75	8·62 7·00 7·76
Mean - - -	-	-	- - -	16·98	·161	1·303	13·13	7·79
Cornish boiler, cylindrical, 36 to 40 feet long, weighing 12 to 13 tons each.	2 3 4	3 3 4	Hual Towan United Mines Old Ford	36·11 43·88 43·70	1·205 1·022 1·560	12·75 10·72 13·1	2·83 4·09 3·64	10·58 10·48 8·52
Mean - - -	-	-	- - -	41·23	1·262	11·85	3·52	9·89

By this Table, it appears that, in the Cornish boiler,

1. The ratio of the area of the heating surface to that of the fire grate is more than double what it is in the common boiler.
2. The proportion of heating surface to the quantity of water evaporated, or of fuel consumed, is about ten times as great.
3. The ratio of combustion is slower with the Cornish boiler than with the common one, in the ratio of 1 to 4.
4. There is an economy of about 27 per cent. in fuel by the use of the Cornish system of boilers, as compared with ordinary land boilers; though they are less economical, as has been shown by the trials at the Blackwall Railway, than marine boilers, having the same amount of surface.

Although a great economy of fuel is gained by the Cornish boiler, it is important to observe that this advantage is attended with a loss of time. Thus, one waggon-shaped boiler at the Albion Mills, weighing only 7½ tons, evaporated 55 cubic feet of water per hour; while three cylindrical or Cornish boilers, weighing 48 tons, evaporate only 48 cubic feet. This is chiefly the result of the system of firing practised with the one boiler and not with the other. Again, in estimating the different qualities of the two classes of boilers from a table containing practical data, as the one we have given, it ought to be remembered that the average pressure of the steam in the Cornish boiler is greater than the average pressure of steam in the waggon boiler. The high pressure of the steam in the Cornish boiler requires the maintenance of a higher temperature in and about the boiler, and consequently there would be greater losses from dispersion, but for the effectual kind of clothing employed in the Cornish engines and boilers, and to which no inconsiderable part of their economy is to be attributed. It appears probable to us that the marine tubular boiler, or the tubular boiler with upright tubes, will supersede the Cornish boiler; and the exchange, it can hardly be doubted, would be an improvement; for with the same economy there would be a saving of weight and a saving also of the expense of setting. Indeed in the case of all land boilers, this expense will probably be hereafter saved by the substitution of the marine form of boiler for that which has heretofore been adopted.

With these remarks we leave the subject of boilers, where we have perhaps lingered too long. We may mention that, although a great deal of attention and engineering ingenuity has been bestowed upon the improvement of boilers, there still remains great scope for improvement. Indeed, although some few engineers have spent a good deal of attention and ingenuity upon the subject of boilers and furnaces, still it is much to be lamented that the aim of so many others is no higher than to follow closely in the footsteps of their predecessors. The rule of the great majority of constructors seems to be to follow as closely as circumstances will permit that which has been found to answer. The blind submission which they display to the maxims of their predecessors, and their servile imitation of their maxims, has hitherto operated as an almost impenetrable barrier against extensive improvement in this most important department of engineering. Indeed we ought not to expect any other result. No improvement can reasonably be expected in any art or science, unless some judicious departures be made from the common methods. The construction of the boiler of a locomotive engine affords a striking example of the amount of improvement which may sometimes be made by judicious experiment, and the extension of this principle to marine boilers, which has now been accomplished, is an important step in the right direction. Nevertheless much remains to be done both as regards the distribution of heat-receiving surface in the best manner, and the introduction of improved means of feeding the fire with coals. The modes of feeding the fire at present in use are far from satisfactory, and in steam vessels particularly are the occasion of great labour and expense, all of which could be obviated by the introduction of some automatic machinery, by which the engine would supply the furnaces with the fuel they require. The revolving grate described in page 53, with its accompanying apparatus, is the self-acting fire-feeder to which we think a preference should be given; and in the boiler with upright tubes described at page 69 the revolving grate is of easy application. Experiments with these upright tubes has shown that they are considerably more efficacious than tubes lying horizontally, while their use is attended with various collateral advantages. For locomotives, boilers with short upright tubes would be preferable to the ordinary plan of locomotive boilers: a large fire surface would then be obtainable, and but little power would require to be wasted upon the blast.

TABLE OF DIMENSIONS OF THE PRINCIPAL PARTS OF MESSRS. MAUDSLAY, SONS, AND FIELD'S MARINE ENGINES.

Names of Parts.	Nominal Power of Engine.													
	10 H. P.	15 H. P.	20 H. P.	25 H. P.	30 H. P.	40 H. P.	50 H. P.	60 H. P.	70 H. P.	80 H. P.	90 H. P.	100 H. P.	110 H. P.	120 H. P.
Diameter of	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
Cylinder - - - - -	20	24	27	29½	32	36½	40	43	46	48	50	52½	55½	57
Piston-rod - - - -	2	2⅝	2¾	3	3¼	3½	4	4¼	4½	4¾	4⅞	5	5¼	5½
Air-pump - - - -	12	15	17	17½	18½	21	23	24	26	27½	28	30	31½	34
Air-pump rod - - - -	1¼	1¾	2	2⅛	2¼	2½	2¾	2⅞	3	3¼	3½	3¾	4	4¼
Injection-cock - - - -	1¼	1½	1⅝	1¾	2	2¼	2½	2¾	3	3⅛	3¼	3¼	3⅜	3½
Hot-water pump - - - -	2¼	2½	3	3¼	3½	4	4¼	4½	5	5½	6	6½	7	7½
Feed-pipe - - - -	1½	1¾	2	2⅛	2¼	2½	2½	2¾	3	3¼	3¼	3½	3½	4
Steam-pipe - - - -	4	5	5¾	6	6½	7	7¾	8½	9¼	10	10½	11	11½	12
Waste water-pipe - - -	5	6	7	7½	8	9	9½	10	10½	11½	12¼	13	13½	14
Beam gudgeon - - - -	3½	4¼	5	5¼	5½	6	6½	7	7½	8	8½	9	9½	9¾
Pins in beam ends - - -	2	2⅝	2¾	3	3¼	3½	4	4¼	4½	4½	5	5¼	5¼	5½
Air-pump pins in beam - - -	1¼	1⅝	1¾	1⅞	2	2¼	2½	2½	2⅞	2⅞	3	3⅛	3⅛	3¼
Crank-pin - - - -	2½	3	3½	3¾	4	4½	5	5½	6	6½	7	7⅜	7¾	8
Main shaft - - - -	4¼	5½	6¼	6¾	7	7½	8½	9¼	10	10¼	10½	11½	12	12½
Paddle-wheels, in feet - - -	9	11	11	12	13	13	15	17	17	19	19	21	21	23
Weigh-shaft bearings - - -	2	2¼	2½	2½	2⅝	2¾	2¾	2¾	3	3¼	3¼	3½	3¾	3¾
Stroke of														
Piston - - - - -	24	30	30	33	36	36	42	48	52	56	60	63	66	72
Air-pump bucket - - -	12	15	15	16½	18	18	21	24	26	28	30	31½	33	36
Feed-pump plunger - - -	6	7½	7½	8	9	9	10½	12	13	14	15	16	16½	18
Cylinder cross head,														
Depth of boss - - - -	6	7½	8	9	9½	10½	12	13	14	14½	15	16	17	17½
Diameter of boss - - - -	4	4½	5	5½	6	6¾	7½	8	8¾	9	9½	10	11	12
Depth of middle - - - -	5	5½	6¼	7	7½	8½	9½	10¼	11½	11¾	12½	13	13½	14
Thickness - - - -	1½	1⅝	1¾	2	2¼	2½	2¾	3	3¼	3½	3½	3¾	4	4⅛
Air-pump cross head,														
Depth of boss - - - -	4½	5	5½	6⅛	6¾	8	9	10	10½	10¾	11	11½	12	12½
Diameter of boss - - - -	2¾	3⅜	3½	4	4⅛	4⅝	5⅛	5¼	5¾	6	6½	6¾	7¼	7½
Depth of middle - - - -	3½	4	4½	5	5¼	6¼	7	7⅝	8	8¼	8½	9	9¼	9½
Thickness - - - -	1	1⅛	1¼	1⅜	1½	1¾	2	2⅛	2¼	2¼	2⅜	2½	2¾	2¾
Columns,														
Diameter at top - - - -	4	4¾	5⅛	5½	6	7	8	8¼	9⅛	9¼	9½	10	10¼	10½
Diameter at bottom - - -	4½	5½	6¼	6⅝	6¾	7¾	9	9⅝	10½	10¾	11	11½	11¾	12
Centre to centre of														
Air-pump, side-rods transversely - -	29½	34¼	37¼	39¼	42¼	47½	53	55¾	60¾	63	67	68½	70	72
Beams, ditto - - - -	33	39	42½	45	48	54	60	68	69	69	72	78	80	83
Frames, ditto - - - -	21	23	25½	26	27	30	34	34	40	40	42	44	45	46
Engines, ditto - - - -	66	72	76	80	84	88	96	100	108	108	112	126	128	130
Length of steam port - - -	7½	8¾	10	11	11½	13	15	18½	18½	19	19	20	20	21
Breadth of steam port - - -	1½	1¾	2	2¼	2½	2¾	3	3	4	4	4¼	4½	4¾	4¾
Fort valve passage,														
Depth - - - - -	2	2	2½	2½	3¼	3¾	4	4½	5	5¼	5½	6	6½	7
Width - - - - -	13	14	15½	17	18	20	24	26	28	28	29	31	31	32
Beam,														
Breadth at middle - - -	14	18	19	21	23	25	28	29	33	34	35	36	38	39
Breadth at ends - - - -	5		6¾	7½	8	8¾	10	10½	12	12¼	12¾	14	15	15½
Thickness - - - -	1	1⅛	1⅓	1⅜	1½	1¾	1⅞	2	2¼	2⅜	2½	2½	2½	2⅝

TABLE OF THE DIMENSIONS OF MARINE STEAM ENGINES OF MESSRS. SEAWARD AND CO.'S MANUFACTURE.

Power.	Diameter of Cylinder.	Diameter of Air Pump.	Stroke.		Diameter of Paddle Wheel.	Diameter of Main Shaft.	Depth of Boss of Cross Head.	Diameter of Piston Rod.	Diameter of Air-pump Rod, Copper.	Diameter of Air-pump Rod, Iron.	Diameter of Steam Pipe.	Number of Lbs. Plate for Steam Pipe.	Diameter of Waste Water Pipe.	Diameter of Feed Pipe.	Length of Beam.		Bearing of Cross Head (Diameter).	Main-beam Gudgeon.	Radius Rod Bearing.	Weigh Shaft, Length of Bearing.	Weigh Shaft, Diameter of Bearings.	Diameter of Crank Pin.	Length of Crank Pin.
			ft.	in.											ft.	in.							
10	20	12	2	0	9	4	7	2	1¼	1	4	26	5	1½	6	0	2	3	1⅜	2½	2	2½	2¾
15	24	15	2	6	11	4¾	8½	2½	1¼	1¼	5	28	6	1¾	7	0	2¼	4	1½	2½	2¼	3	3¼
20	27	17	2	6	11	5¾	10	3	1¾	1½	5¾	30	7	2	8	0	2½	5	1¾	3	2½	3½	3½
30	31¾	18½	3	0	13	6¾	10¾	3¼	1⅞	1¾	6½	35	8	2¼	8	8	2¾	5½	2	3½	2½	4	4¼
40	36½	20	3	0	13	7½	11½	3½	2¼	·1⅞	7	38	9	2½	10	0	3	6	2¼	3½	2¾	4½	4¾
50	39½	22	3	6	15	8¼	12¼	3¾	2½	2	7¾	40	9½	2¾	10	6	3¼	6½	2½	3¾	2¾	5	5¼
60	43	24	4	0	17	9	13	4	2¾	2¼	8½	44	10	3	11	6	3½	7	2¾	4	2¾	5½	6
70	46	25½	4	3	17	9½	13¾	4¼	3	2½	9¼	50	10	3¼	12	6	3¾	7½	3	4¼	3	6	6½
80	48	27	4	6	19	10	14½	4½	3¼	2¾	10	55	11	3½	13	0	4	8	3¼	4½	4¼	6½	7
90	50	28	4	9	19	10½	15¼	4¾	3½	3	10½	58	12½	3¾	13	6	4¼	8½	3½	4¾	3¼	7	7½
100	52½		5	0	21	11	16	5	3¾	3⅛	11	62	13	4	16	0	4½	9	3⅝	5	3½	7¾	7¾
110	55		5	0	21	11½	16¾	5¼	4	3¼	11½	66	13½	4¼	16	0	4¾	9½	3¾	5¼	3¾	7¾	8¼
120	57½		5	6	23	12½	17½	5½	4¼	3½	12	70	14	4½	17	6	5	9¾	3⅞	5½	3¾	8	8½

TABLE OF CIRCUMFERENCES FOR ANGLED IRON HOOPS.

ANGLE OUTSIDE.

Diam.	Circum.	Diam.	Circum.	Diam.	Circum.	Diam.	Circum.	Diam.	Circum.	Diam.	Circum.	Diam.	Circum.	Diam.	Circum.	Diam.	Circum.	Diam.	Circum.
ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
6	1 5½	1 1	3 2	1 8	4 10⅝	2 3	6 7⅛	2 10	8 3⅝	3 5	10 0⅛	4 0	11 8⅝	4 7	13 5⅛	5 2	15 1⅝	5 9	16 10¼
⅛	1 5⅞	⅛	3 2⅜	⅛	4 11	⅛	6 7½	⅛	8 4	⅛	10 0½	⅛	11 9	⅛	13 5½	⅛	15 2	⅛	16 10½
¼	1 6¼	¼	3 2¾	¼	4 11⅜	¼	6 7⅞	¼	8 4⅜	¼	10 0⅞	¼	11 9⅜	¼	13 5⅞	¼	15 2⅜	¼	16 10⅞
⅜	1 6⅝	⅜	3 3⅛	⅜	4 11⅝	⅜	6 8⅛	⅜	8 4¾	⅜	10 1¼	⅜	11 9¾	⅜	13 6¼	⅜	15 2¾	⅜	16 11¼
½	1 7	½	3 3½	½	5 0	½	6 8½	½	8 5⅛	½	10 1⅝	½	11 10⅛	½	13 6⅝	½	15 3⅛	½	16 11⅝
⅝	1 7⅜	⅝	3 3⅞	⅝	5 0⅜	⅝	6 8⅞	⅝	8 5½	⅝	10 2	⅝	11 10½	⅝	13 7	⅝	15 3½	⅝	17 0
¾	1 7¾	¾	3 4¼	¾	5 0¾	¾	6 9¼	¾	8 5¾	¾	10 2⅜	¾	11 10⅞	¾	13 7⅜	¾	15 3⅞	¾	17 0⅜
⅞	1 8⅛	⅞	3 4⅝	⅞	5 1⅛	⅞	6 9⅝	⅞	8 6⅛	⅞	10 2¾	⅞	11 11¼	⅞	13 7¾	⅞	15 4¼	⅞	17 0¾
7	1 8½	1 2	3 5	1 9	5 1½	2 4	6 10	2 11	8 6½	3 6	10 3	4 1	11 11⅝	4 8	13 8⅛	5 3	15 4⅝	5 10	17 1⅛
⅛	1 8⅞	⅛	3 5⅜	⅛	5 1⅞	⅛	6 10⅜	⅛	8 6⅞	⅛	10 3⅜	⅛	12 0	⅛	13 8½	⅛	15 5	⅛	17 1½
¼	1 9¼	¼	3 5¾	¼	5 2¼	¼	6 10¾	¼	8 7¼	¼	10 3¾	¼	12 0¼	¼	13 8⅞	¼	15 5⅜	¼	17 1⅞
⅜	1 9½	⅜	3 6⅛	⅜	5 2⅝	⅜	6 11⅛	⅜	8 7⅝	⅜	10 4⅛	⅜	12 0⅝	⅜	13 9¼	⅜	15 5¾	⅜	17 2¼
½	1 9⅞	½	3 6½	½	5 3	½	6 11½	½	8 8	½	10 4½	½	12 1	½	13 9⅝	½	15 6⅛	½	17 2⅝
⅝	1 10¼	⅝	3 6⅞	⅝	5 3⅜	⅝	6 11⅞	⅝	8 8⅜	⅝	10 4⅞	⅝	12 1⅜	⅝	13 9⅞	⅝	15 6½	⅝	17 3
¾	1 10⅝	¾	3 7⅛	¾	5 3¾	¾	7 0¼	¾	8 8¾	¾	10 5¼	¾	12 1¾	¾	13 10¼	¾	15 6⅞	¾	17 3⅜
⅞	1 11	⅞	3 7½	⅞	5 4	⅞	7 0⅝	⅞	8 9⅛	⅞	10 5⅝	⅞	12 2⅛	⅞	13 10⅝	⅞	15 7⅛	⅞	17 3¾
8	1 11⅜	1 3	3 7⅞	1 10	5 4⅜	2 5	7 1	3 0	8 9½	3 7	10 6	4 2	12 2½	4 9	13 11	5 4	15 7½	5 11	17 4
⅛	1 11¾	⅛	3 8¼	⅛	5 4¾	⅛	7 1⅜	⅛	8 9⅞	⅛	10 6⅜	⅛	12 2⅞	⅛	13 11⅜	⅛	15 7⅞	⅛	17 4⅜
¼	2 0⅛	¼	3 8⅝	¼	5 5⅛	¼	7 1¾	¼	8 10¼	¼	10 6¾	¼	12 3¼	¼	13 11¾	¼	15 8¼	¼	17 4¾
⅜	2 0½	⅜	3 9	⅜	5 5½	⅜	7 2	⅜	8 10⅝	⅜	10 7⅛	⅜	12 3⅝	⅜	14 0⅛	⅜	15 8⅝	⅜	17 5⅛
½	2 0⅞	½	3 9⅜	½	5 5⅞	½	7 2⅜	½	8 11	½	10 7½	½	12 4	½	14 0½	½	15 9	½	17 5½
⅝	2 1¼	⅝	3 9¾	⅝	5 6¼	⅝	7 2¾	⅝	8 11¼	⅝	10 7⅞	⅝	12 4⅜	⅝	14 0⅞	⅝	15 9⅜	⅝	17 5⅞
¾	2 1⅝	¾	3 10⅛	¾	5 6⅝	¾	7 3⅛	¾	8 11⅝	¾	10 8¼	¾	12 4¾	¾	14 1¼	¾	15 9¾	¾	17 6¼
⅞	2 2	⅞	3 10½	⅞	5 7	⅞	7 3½	⅞	9 0	⅞	10 8½	⅞	12 5⅛	⅞	14 1⅝	⅞	15 10⅛	⅞	17 6⅝
9	2 2⅜	1 4	3 10⅞	1 11	5 7⅜	2 6	7 3⅞	3 1	9 0⅜	3 8	10 8⅞	4 3	12 5½	4 10	14 2	5 5	15 10½	6 0	17 7
⅛	2 2⅝	⅛	3 11¼	⅛	5 7¾	⅛	7 4¼	⅛	9 0¾	⅛	10 9¼	⅛	12 5¾	⅛	14 2⅝	⅛	15 10⅞		
¼	2 3	¼	3 11⅝	¼	5 8⅛	¼	7 4⅝	¼	9 1⅛	¼	10 9⅝	¼	12 6⅛	¼	14 2¾	¼	15 11¼		
⅜	2 3⅜	⅜	3 11⅞	⅜	5 8½	⅜	7 5	⅜	9 1½	⅜	10 10	⅜	12 6½	⅜	14 3	⅜	15 11⅝		
½	2 3¾	½	4 0¼	½	5 8⅞	½	7 5⅜	½	9 1⅞	½	10 10⅜	½	12 6⅞	½	14 3⅜	½	16 0		
⅝	2 4⅛	⅝	4 0⅝	⅝	5 9¼	⅝	7 5¾	⅝	9 2¼	⅝	10 10¾	⅝	12 7¼	⅝	14 3¾	⅝	16 0¼		
¾	2 4½	¾	4 1	¾	5 9⅝	¾	7 6⅛	¾	9 2⅝	¾	10 11⅛	¾	12 7⅝	¾	14 4⅛	¾	16 0⅝		
⅞	2 4⅞	⅞	4 1⅜	⅞	5 9⅞	⅞	7 6½	⅞	9 3	⅞	10 11½	⅞	12 8	⅞	14 4½	⅞	16 1		
10	2 5¼	1 5	4 1¾	2 0	5 10¼	2 7	7 6⅞	3 2	9 3⅜	3 9	10 11⅞	4 4	12 8⅜	4 11	14 4⅞	5 6	16 1⅜		
⅛	2 5⅝	⅛	4 2⅛	⅛	5 10⅝	⅛	7 7⅛	⅛	9 3¾	⅛	11 0¼	⅛	12 8¾	⅛	14 5¼	⅛	16 1¾		
¼	2 6	¼	4 2½	¼	5 11	¼	7 7½	¼	9 4⅛	¼	11 0⅝	¼	12 9⅛	¼	14 5⅝	¼	16 2⅛		
⅜	2 6⅜	⅜	4 2⅞	⅜	5 11⅜	⅜	7 7⅞	⅜	9 4⅜	⅜	11 1	⅜	12 9½	⅜	14 6	⅜	16 2½		
½	2 6¾	½	4 3¼	½	5 11¾	½	7 8¼	½	9 4¾	½	11 1⅜	½	12 9⅞	½	14 6⅜	½	16 2⅞		
⅝	2 7⅛	⅝	4 3⅝	⅝	6 0⅛	⅝	7 8⅝	⅝	9 5⅛	⅝	11 1¾	⅝	12 10¼	⅝	14 6¾	⅝	16 3¼		
¾	2 7½	¾	4 4	¾	6 0½	¾	7 9	¾	9 5½	¾	11 2	¾	12 10½	¾	14 7⅛	¾	16 3⅝		
⅞	2 7⅞	⅞	4 4⅜	⅞	6 0⅞	⅞	7 9⅜	⅞	9 5⅞	⅞	11 2⅜	⅞	12 10⅞	⅞	14 7½	⅞	16 4		
11	2 8⅛	1 6	4 4¾	2 1	6 1¼	2 8	7 9¾	3 3	9 6¼	3 10	11 2¾	4 5	12 11¼	5 0	14 7⅞	5 7	16 4⅜		
⅛	2 8½	⅛	4 5⅛	⅛	6 1⅝	⅛	7 10⅛	⅛	9 6⅝	⅛	11 3⅛	⅛	12 11⅝	⅛	14 8⅛	⅛	16 4¾		
¼	2 8⅞	¼	4 5⅜	¼	6 2	¼	7 10½	¼	9 7	¼	11 3½	¼	13 0	¼	14 8½	¼	16 5⅛		
⅜	2 9¼	⅜	4 5¾	⅜	6 2⅜	⅜	7 10⅞	⅜	9 7⅜	⅜	11 3⅞	⅜	13 0⅜	⅜	14 8⅞	⅜	16 5⅜		
½	2 9⅝	½	4 6⅛	½	6 2¾	½	7 11¼	½	9 7¾	½	11 4¼	½	13 0¾	½	14 9¼	½	16 5¾		
⅝	2 10	⅝	4 6½	⅝	6 3	⅝	7 11⅝	⅝	9 8⅛	⅝	11 4⅝	⅝	13 1⅛	⅝	14 9⅝	⅝	16 6⅛		
¾	2 10⅜	¾	4 6⅞	¾	6 3⅜	¾	8 0	¾	9 8½	¾	11 5	¾	13 1½	¾	14 10	¾	16 6½		
⅞	2 10¾	⅞	4 7¼	⅞	6 3¾	⅞	8 0⅜	⅞	9 8⅞	⅞	11 5⅜	⅞	13 1⅞	⅞	14 10⅜	⅞	16 6⅞		
1 0	2 11⅛	1 7	4 7⅝	2 2	6 4⅛	2 9	8 0⅝	3 4	9 9¼	3 11	11 5¾	4 6	13 2¼	5 1	14 10¾	5 8	16 7¼		
⅛	2 11½	⅛	4 8	⅛	6 4½	⅛	8 1	⅛	9 9½	⅛	11 6⅛	⅛	13 2⅝	⅛	14 11⅛	⅛	16 7⅝		
¼	2 11⅞	¼	4 8⅜	¼	6 4⅞	¼	8 1⅜	¼	9 9⅞	¼	11 6½	¼	13 3	¼	14 11½	¼	16 8		
⅜	2 0¼	⅜	4 8¾	⅜	6 5¼	⅜	8 1¾	⅜	9 10¼	⅜	11 6⅞	⅜	13 3⅜	⅜	14 11⅞	⅜	16 8⅜		
½	3 0⅝	½	4 9⅛	½	6 5⅝	½	8 2⅛	½	9 10⅝	½	11 7⅛	½	13 3¾	½	15 0¼	½	16 8¾		
⅝	3 1	⅝	4 9½	⅝	6 6	⅝	8 2½	⅝	9 11	⅝	11 7½	⅝	13 4⅛	⅝	15 0⅝	⅝	16 9⅛		
¾	3 1⅜	¾	4 9⅞	¾	6 6⅜	¾	8 2⅞	¾	9 11⅜	¾	11 7⅞	¾	13 4⅜	¾	15 1	¾	16 9½		
⅞	3 1¾	⅞	4 10¼	⅞	6 6¾	⅞	8 3¼	⅞	9 11¾	⅞	11 8¼	⅞	13 4¾	⅞	15 1⅜	⅞	16 9⅞		

DIMENSIONS OF ENGINES.

Having thus far disposed of the subject of boilers, there may be no great impropriety, before entering at length upon the subject of engines, to set down some of the chief dimensions of marine and locomotive engines, the locomotive boiler and engine being so identified, that it is difficult to separate the consideration of them. We first give a table of the dimensions of Messrs. Maudslay and Co's side lever marine engines, and another of the dimensions of Messrs. Seaward and Co's. We do not attach any great importance to these dimensions, yet it is satisfactory to be in possession of the dimensions used by makers of some reputation, though not the best absolutely.

We add some rules and tables for facilitating the construction of boilers, &c., by determining the lengths of plate or angle-iron requisite for the formation of hoops of different diameters. For plate or flat bar:—

Rule. — *Add the thickness of the bar to the required diameter, and the corresponding circumference in the table of circumferences of circles given at page 24. is the length of the bar.*

If the iron be bent edgewise the breadth of the bar must be added to the diameter; for it is the thickness of the bar measured radially that is to be taken into consideration.

In such pieces of work as the tires of railway wheels, which have a flange on one edge, it is necessary to add, not only the thickness of the tire, but also two thirds of the thickness of the flange. Generally, however, the tire bars are sent from the iron works so curved that the plain edge of the

TABLE OF CIRCUMFERENCES FOR ANGLED IRON HOOPS.

ANGLE INSIDE.

Diam.	Circum.	Diam.	Circum.	Diam.	Circum.	Diam.	Circum.	Diam.	Circum.	Diam.	Circum.	Diam.	Circum.	Diam.	Circum.	Diam.	Circum.	Diam.	Circum.
ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
6	1 8½	1 1	3 8½	1 8	5 8½	2 3	7 8⅜	2 10	9 8⅜	3 5	11 8⅜	4 0	13 8⅜	4 7	15 8¼	5 2	17 8¼	5 9	19 8¼
⅛	1 8¾	⅛	3 8⅞	⅛	5 8⅞	⅛	7 8⅞	⅛	9 8⅞	⅛	11 8¾	⅛	13 8¾	⅛	15 8¾	⅛	17 8¾	⅛	19 8⅝
¼	1 9⅜	¼	3 9⅜	¼	5 9¼	¼	7 9¼	¼	9 9¼	¼	11 9¼	¼	13 9¼	¼	15 9⅛	¼	17 9⅛	¼	19 9⅛
⅜	1 9¾	⅜	3 9¾	⅜	5 9¾	⅜	7 9¾	⅜	9 9⅝	⅜	11 9⅝	⅜	13 9⅝	⅜	15 9⅝	⅜	17 9½	⅜	19 9½
½	1 10¼	½	3 10⅛	½	5 10⅛	½	7 10⅛	½	9 10⅛	½	11 10⅛	½	13 10	½	15 10	½	17 10	½	19 10
⅝	1 10⅝	⅝	3 10⅝	⅝	5 10⅝	⅝	7 10½	⅝	9 10½	⅝	11 10½	⅝	13 10½	⅝	15 10½	⅝	17 10⅜	⅝	19 10⅜
¾	1 11⅛	¾	3 11	¾	5 11	¾	7 11	¾	9 11	¾	11 10⅞	¾	13 10⅞	¾	15 10⅞	¾	17 10⅞	¾	19 10⅞
⅞	1 11⅜	⅞	3 11⅜	⅞	5 11⅜	⅞	7 11⅜	⅞	9 11⅜	⅞	11 11⅜	⅞	13 11⅜	⅞	15 11¼	⅞	17 11¼	⅞	19 11¼
7	1 11⅞	1 2	3 11⅞	1 9	5 11⅞	2 4	7 11¾	2 11	9 11⅞	3 6	11 11¾	4 1	13 11¾	4 8	15 11¾	5 3	17 11¾	5 10	19 11⅝
⅛	2 0⅜	⅛	4 0⅜	⅛	6 0¼	⅛	8 0¼	⅛	10 0¼	⅛	12 0¼	⅛	14 0¼	⅛	16 0⅛	⅛	18 0⅛	⅛	20 0⅛
¼	2 0¾	¼	4 0¾	¼	6 0¾	¼	8 0¾	¼	10 0⅝	¼	12 0⅝	¼	14 0⅝	¼	16 0⅝	¼	18 0½	¼	20 0½
⅜	2 1¼	⅜	4 1⅛	⅜	6 1⅛	⅜	8 1⅛	⅜	10 1⅛	⅜	12 1⅛	⅜	14 1	⅜	16 1	⅜	18 1	⅜	20 1
½	2 1⅝	½	4 1⅝	½	6 1⅝	½	8 1½	½	10 1½	½	12 1½	½	14 1½	½	16 1½	½	18 1⅜	½	20 1⅜
⅝	2 2	⅝	4 2	⅝	6 2	⅝	8 2	⅝	10 2	⅝	12 1⅞	⅝	14 1⅞	⅝	16 1⅞	⅝	18 1⅞	⅝	20 1⅞
¾	2 2½	¾	4 2½	¾	6 2½	¾	8 2⅜	¾	10 2⅜	¾	12 2⅜	¾	14 2⅜	¾	16 2¼	¾	18 2¼	¾	20 2¼
⅞	2 2⅞	⅞	4 2⅞	⅞	6 2⅞	⅞	8 2¾	⅞	10 2¾	⅞	12 2¾	⅞	14 2¾	⅞	16 2¾	⅞	18 2¾	⅞	20 2⅝
8	2 3⅜	1 3	4 3⅜	1 10	6 3¼	2 5	8 3¼	3 0	10 3¼	3 7	12 3¼	4 2	14 3½	4 9	16 3⅛	5 4	18 3⅛	5 11	20 3⅛
⅛	2 3¾	⅛	4 3¾	⅛	6 3¾	⅛	8 3⅝	⅛	10 3⅝	⅛	12 3⅝	⅛	14 3	⅛	16 3⅝	⅛	18 3½	⅛	20 3½
¼	2 4¼	¼	4 4⅛	¼	6 4⅛	¼	8 4⅛	¼	10 4⅛	¼	12 4⅛	¼	14 4	¼	16 4	¼	18 4	¼	20 4
⅜	2 4⅝	⅜	4 4⅝	⅜	6 4⅝	⅜	8 4½	⅜	10 4½	⅜	12 4½	⅜	14 4½	⅜	16 4½	⅜	18 4⅜	⅜	20 4⅜
½	2 5	½	4 5	½	6 5	½	8 5	½	10 5	½	12 4⅞	½	14 4⅞	½	16 4⅞	½	18 4⅞	½	20 4¾
⅝	2 5½	⅝	4 5½	⅝	6 5⅜	⅝	8 5½	⅝	10 5⅜	⅝	12 5⅜	⅝	14 5⅜	⅝	16 5¼	⅝	18 5¼	⅝	20 5¼
¾	2 5⅞	¾	4 5⅞	¾	6 5⅞	¾	8 5⅞	¾	10 5⅞	¾	12 5¾	¾	14 5¾	¾	16 5¾	¾	18 5¾	¾	20 5⅝
⅞	2 6⅜	⅞	4 6¼	⅞	6 6¼	⅞	8 6¼	⅞	10 6¼	⅞	12 6¼	⅞	14 6⅛	⅞	16 6⅛	⅞	18 6⅛	⅞	20 6⅛
9	2 6¾	1 4	4 6¾	1 11	6 6¾	2 6	8 6¾	3 1	10 6⅝	3 8	12 6⅝	4 3	14 6⅝	4 10	16 6⅝	5 5	18 6½	6 0	20 6½
⅛	2 7¼	⅛	4 7⅛	⅛	6 7⅛	⅛	8 7⅛	⅛	10 7⅛	⅛	12 7	⅛	14 7	⅛	16 7	⅛	18 7		
¼	2 7⅝	¼	4 7⅝	¼	6 7⅝	¼	8 7½	¼	10 7½	¼	12 7½	¼	14 7⅜	¼	16 7⅜	¼	18 7⅜		
⅜	2 8	⅜	4 8	⅜	6 8	⅜	8 8	⅜	10 8	⅜	12 7⅞	⅜	14 7⅞	⅜	16 7⅞	⅜	18 7⅞		
½	2 8½	½	4 8½	½	6 8⅜	½	8 8⅜	½	10 8⅜	½	12 8⅜	½	14 8⅜	½	16 8¼	½	18 8¼		
⅝	2 8⅞	⅝	4 8⅞	⅝	6 8⅞	⅝	8 8⅞	⅝	10 8¾	⅝	12 8¾	⅝	14 8¾	⅝	16 8¾	⅝	18 8¾		
¾	2 9⅜	¾	4 9⅜	¾	6 9¼	¾	8 9¼	¾	10 9¼	¾	12 9¼	¾	14 9⅛	¾	16 9⅛	¾	18 9⅛		
⅞	2 9¾	⅞	4 9¾	⅞	6 9¾	⅞	8 9⅝	⅞	10 9⅝	⅞	12 9⅝	⅞	14 9⅝	⅞	16 9⅝	⅞	18 9½		
10	2 10¼	1 5	4 10⅛	2 0	6 10⅛	2 7	8 10⅛	3 2	10 10⅛	3 9	12 10	4 4	14 10	4 11	16 10	5 6	18 10		
⅛	2 10⅝	⅛	4 10⅝	⅛	6 10½	⅛	8 10½	⅛	10 10½	⅛	12 10½	⅛	14 10½	⅛	16 10⅜	⅛	18 10⅜		
¼	2 11	¼	4 11	¼	6 11	¼	8 11	¼	10 11	¼	12 10⅞	¼	14 10⅞	¼	16 10⅞	¼	18 10⅞		
⅜	2 11½	⅜	4 11½	⅜	6 11⅜	⅜	8 11⅜	⅜	10 11⅜	⅜	12 11⅜	⅜	14 11⅜	⅜	16 11¼	⅜	18 11¼		
½	2 11⅞	½	4 11⅞	½	6 11⅞	½	8 11⅞	½	10 11¾	½	12 11¾	½	14 11¾	½	16 11¾	½	18 11¾		
⅝	3 0⅜	⅝	5 0¼	⅝	7 0¼	⅝	9 0¼	⅝	11 0¼	⅝	13 0¼	⅝	15 0⅛	⅝	17 0⅛	⅝	19 0⅛		
¾	3 0¾	¾	5 0¾	¾	7 0¾	¾	9 0⅝	¾	11 0⅝	¾	13 0⅝	¾	15 0⅝	¾	17 0⅝	¾	19 0½		
⅞	3 1¼	⅞	5 1⅛	⅞	7 1⅛	⅞	9 1⅛	⅞	11 1⅛	⅞	13 1	⅞	15 1	⅞	17 1	⅞	19 1		
11	3 1⅝	1 6	5 1⅝	2 1	7 1⅝	2 8	9 1½	3 3	11 1½	3 10	13 1½	4 5	15 1½	5 0	17 1½	5 7	19 1⅜		
⅛	3 2	⅛	5 2	⅛	7 2	⅛	9 2	⅛	11 2	⅛	13 1⅞	⅛	15 1⅞	⅛	17 1⅞	⅛	19 1⅞		
¼	3 2½	¼	5 2½	¼	7 2⅜	¼	9 2⅜	¼	11 2⅜	¼	13 2⅜	¼	15 2¼	¼	17 2¼	¼	19 2¼		
⅜	3 3⅞	⅜	5 2⅞	⅜	7 2⅞	⅜	9 2⅞	⅜	11 2¾	⅜	13 2¾	⅜	15 2¾	⅜	17 2¾	⅜	19 2¾		
½	3 3⅜	½	5 3¼	½	7 3¼	½	9 3¼	½	11 3¼	½	13 3¼	½	15 3⅛	½	17 3⅛	½	19 3⅛		
⅝	3 3¾	⅝	5 3¾	⅝	7 3¾	⅝	9 3⅝	⅝	11 3⅝	⅝	13 3⅝	⅝	15 3⅝	⅝	17 3⅝	⅝	19 3½		
¾	3 4¼	¾	5 4⅛	¾	7 4⅛	¾	9 4⅛	¾	11 4⅛	¾	13 4	¾	15 4	¾	17 4	¾	19 4		
⅞	3 4⅝	⅞	5 4⅝	⅞	7 4½	⅞	9 4½	⅞	11 4½	⅞	13 4½	⅞	15 4½	⅞	17 4⅜	⅞	19 4⅜		
1 0	3 5	1 7	5 5	2 2	7 5	2 9	9 5	3 4	11 5	3 11	13 4⅞	4 6	15 4⅞	5 1	17 4⅞	5 8	19 4⅞		
⅛	3 5½	⅛	5 5½	⅛	7 5⅜	⅛	9 5⅜	⅛	11 5⅜	⅛	13 5⅜	⅛	15 5¼	⅛	17 5¼	⅛	19 5¼		
¼	3 5⅞	¼	5 5⅞	¼	7 5⅞	¼	9 5⅞	¼	11 5¾	¼	13 5¾	¼	15 5¾	¼	17 5¾	¼	19 5¾		
⅜	3 6⅜	⅜	5 6¼	⅜	7 6¼	⅜	9 6¼	⅜	11 6¼	⅜	13 6¼	⅜	15 6⅛	⅜	17 6⅛	⅜	19 6⅛		
½	3 6¾	½	5 6¾	½	7 6¾	½	9 6⅝	½	11 6⅝	½	13 6⅝	½	15 6⅝	½	17 6½	½	19 6½		
⅝	3 7⅛	⅝	5 7⅛	⅝	7 7⅛	⅝	9 7⅛	⅝	11 7⅛	⅝	13 7	⅝	15 7	⅝	17 7	⅝	19 7		
¾	3 7⅝	¾	5 7½	¾	7 7½	¾	9 7½	¾	11 7½	¾	13 7½	¾	15 7½	¾	17 7⅜	¾	19 7⅜		
⅞	3 8	⅞	5 8	⅞	7 8	⅞	9 8	⅞	11 8	⅞	13 7⅞	⅞	15 7⅞	⅞	17 7⅞	⅞	19 7⅞		

tire is concave, and the flange edge convex; while the side which is afterwards to be bent into contact with the cylindrical surface of the wheel is a plane. By this means the addition to the diameter of two thirds the thickness of the flange is unnecessary: for the curving of the flange edge has the effect of increasing the real length when only the chord of the arc is measured for the circumference. The radius of the curve in which the tires are first bent may be safely taken as four times the circumference of the hoop or wheel. In the form of rules, these results will be, first:—when the tire is straight

RULE.—*Add the thickness of the hoop, and two-thirds the thickness of the flange to the diameter, and find the corresponding circumference.*

And when the tire is curved it will be:—

RULE.—*Add the thickness of the hoop to the diameter, and find the circumference.*

In calculating the length of angle iron required for a given diameter the tables given above, obtained from a work by Mr. Foden, which is little known, are to be used instead of the table of circumferences of circles. The first of these is for iron, in which the angle or flange is outside, and the second for iron, in which the angle or flange is inside. When the angle is outside, its total breadth must be added to the internal diameter, and the circumference found in the table marked, "angle outside." And when the angle is inside, the breadth of the angle must be subtracted from the diameter, which, in this case, is the external diameter, and the circumference found in the table marked, "angle inside." We here add a table of the dimensions of the parts of Locomotives

Table of Dimensions of the Parts of Locomotive Engines.

NAME OF RAILWAY.	Belgium.		Bordeaux and La Teste.		North Midland Counties.		Northern and Eastern Counties.		Great Western.		Hartlepool.	
	ft.	in.	ft.	in.	ft	in.	ft.	in.	ft.	in.	ft.	in.
Width of Railway between rails	4	8½	4	8½	4	8½	5	0	7	0	4	8½
Diameter of boiler (inside)	3	4¾	3	1⅜	3	7¼	3	7¼	3	11¼	3	5¼
Length of ditto	8	2	8	9	8	6	8	0	8	6	8	6
Thickness of plates	0	0⅜	0	0 5/16	0	0⅜	0	0⅜	0	0⅜	0	0⅜
Length of outside fire-box	3	8¾	3	4½	4	0	4	0¼	4	6	3	7
Breadth of ditto	4	0	3	9½	4	0	4	0¼	4	8	4	1
Depth below boiler	2	0	1	8	2	2	2	2	2	3	2	0½
Height above ditto	0	4½	not ascertained		2	7	2	7	2	1	0	4¼
Thickness of plates	0	0⅜	0	0⅜	0	0⅜	0	0⅜	0	0⅜	0	0⅜
Length of *inside* fire-box	3	0¼	2	8	3	3⅝	3	3¾	3	8⅛	2	10½
Breadth of ditto	3	4½	3	2	3	4⅝	3	4¾	3	10⅞	3	5¼
Thickness of copper plates	0	0⅜	0	0⅜	0	0⅜	0	0⅜	0	0½	0	0½
Extra thickness of ditto for insertion of tubes	0	0⅝	0	0⅝	0	0⅝	0	0⅝	0	0⅝	0	0¼
From bottom of fire-box to top of fire-bars	0	8	...		0	9	...		0	9	0	8
From top of fire-bars to crown of fire-box	3	4½	...		3	7½	...		...		3	5
Area of fire-grate in sup. feet	10	2½	...		11	2	11	3	12	10	9	10½
Length of smoke-box (inside)	1	11¾	1	11⅞	2	1	2	1	2	2½	2	1
Breadth of ditto (outside)	3	11¼	4	1	4	2	4	2¾	5	2½	4	2
Thickness of tube plate	0	0½	0	0½	0	0½	0	0½	0	0⅝	0	0½
Ditto of side plates	0	0¼	0	0¼	0	0¼	0	0¼	0	0¼	0	0¼
Diameter of chimney (inside)	1	0¾	1	0	1	2	1	2	1	4	1	2
Height of top of ditto from rails	...		13	0	14	0	13	6	14	10	13	6
Number of brass tubes	86		94		123		121		131		105	
Exterior of diameter of ditto	0	2¼	0	2	115 at 2 8 at 1⅝		0	2	127 at 2 and 4 at 1⅝		0	2
Thickness of tubes.—Wire gauge	No. 14		No. 14		No. 14		No. 14.		No. 12		No. 14	
Distance from centre to centre of tubes	0	3	0	2¾	0	2¾	0	2¾	0	2⅞	0	2¾
Diameter of steam dome (inside)	1	5	...		...		...		...		1	7
Height of ditto	2	7⅝	...		...		...		...		2	7⅝
Diameter of safety valves	2½ and	3	3¼ and	3¼	4 and	4	4 and	4	3¼ and	3¼	2½ and	3
Diameter of inside copper steam-pipe	0	5	0	5	0	6¼	0	6¼	0	6½	0	6¼
Thickness of ditto.—Wire gauge	No. 10		No. 10		...		...		No. 10		No. 10	
Diameter of branch steam pipes (inside)	0	3½	0	3½	0	4⅛	0	4⅛	0	4½	0	4⅛
Diameter of top of blast pipe (inside)	0	2½	0	2½	0	3	0	3	0	3⅝	0	3
Diameter of cylinders	1	0½	1	0	1	2	1	2	1	3	1	2
Length of stroke	1	6	1	6	1	6	1	6	1	6	1	6
Distance of centres of cylinders	2	5	2	5	2	5	2	5	3	0	2	5
Size of steam ports	11 ×	1	9½ ×	1	11 ×	1¼	11 ×	1¼	11 ×	1¼	11 ×	1¼
Ditto of eduction ports	11 ×	2	9½ ×	2	11 ×	2½	11 ×	2½	11 ×	2⅝	11 ×	2½
Breadth of bridge between ports	0	0¾	0	0¾	0	0⅝	0	0⅝	0	0⅝	0	0⅝
Lead of slide valves	0	0 3/16	0	0¼	0	0 3/16	0	0 3/16	...		0	0 3/16
Cover of ditto	0	0 5/16	0	0⅜	0	0½	0	0½	0	0¾	0	0 5/16
Distance from centre of cylinder to centre of steam chest	0	11	...		1	0⅛	1	0⅛	1	2	1	0⅛
Thickness of piston		3⅝		3⅝		4¼		4¼		4		4¼
Diameter of piston rod		2		2		2		2		2¼		2
Ditto of valve spindle		0⅞		1		1		1		1⅛		1
Ditto of pump ram		1⅞		2		2		2		2¼		2
Length of pump lever		6¾	None			6¾		6¾	None			6 5/16
Diameter of ball valves		2		2 7/16		2 7/16		2 7/16		2½		2 7/16
Ditto of union and suction pipes (inside)		1¾		1¾		1¾		1¾		2¼		1¾
Diameter of driving wheels	5	6	6	0	5	0	6	0	7	0	4	6
Tyres of ditto in centre of tread	...		6 ×	1¾	7 ×	1¾	7 ×	1¾	5½ ×	2	5½ ×	1⅝
Diameter of leading wheels	3	9	4	0	5	0	4	0⅝	4	0	4	6
Tyres of ditto	...		5½ ×	1⅝	6 ×	1¾	6 ×	0	5½ ×	2	5½ ×	1⅝
Diameter of trailing wheels	3	9	4	0	3	6	4	0	4	0	None	
Tyres of ditto	...		5½ ×	1⅝	6 ×	1⅝	6 ×	1⅝	5½ ×	2		
Diameter of plain part of cranked axle		4¾		5		5½		5½		6½		5⅞
Ditto of inside bearings		5		5		5¾		5¾		6½		5⅜
Length of ditto	3¼ and	3		3	3¼ and	3	3½ and	3		4		3
Radius of ditto	3 and	2⅜		2⅜	2 13/16 ×	2 9/16	2 9/16 and	2 15/16		5½		2 9/16
Diameter of crank pins		5		5		5¾		5¾		6½		5⅜
Length of ditto		3		3		3		3		4		3
Radius of ditto		2⅜		2⅜		2 9/16		2 9/16		5½		2 9/16
Diameter of outside bearings		3¼		3¼		3¾		3¾		4		3½
Length of ditto		5½		5½		5½		5½		6¾		5½
Diameter of bosses on axle for eccentrics	6⅝ and	4¾	5 and	5	7 and	5½	7 ×	5½	7¼ and	6½	7 ×	5⅞
Ditto of ditto for driving wheels		6⅛		6⅛		6½		6½		7¼		6⅛
Length of ditto for ditto		7½		7⅜		8⅛		7⅞	...			7¼
Diameter of axle for leading wheels		3¾		4		5		4½	6¼ and	4¾		4¾
Ditto of bearings for ditto		3⅛		3⅛		3¾		3¾		3½		3½
Length of ditto for ditto		5½		5½		5½		5½		6¼		5½
Diameter of boss for wheels		4½		5		6½		5½		5¾		5½
Length of boss for ditto		6¾		7		8⅛		7⅝		8		
Diameter of axle for trailing wheels		3¾		4		4½		4½	6¼ ×	4½		
Ditto of bearings		3⅛		3⅛		3¾		3¾		3½		
Length of bearings		5½		5½		5½		5½		6¼		
Diameter of boss for wheels		4½		5		5		5½		5¾		
Length of boss		6¾		7		8		7⅜		8		
Diameter of boss on axle for outside cranks	None		None			4¾	...		None			4½

NAME OF RAILWAY.	Belgium.		Bordeaux and La Teste.		North Midland Counties.		Northern and Eastern Counties.		Great Western.		Hartlepool.	
	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.
Length of boss on axle for outside cranks	...		...			3⅜	...		...			3¼
Length of outside cranks from centre to centre	None		None		1	1½	...		None		1	1½
Diameter of plain pin on ditto	...		...			1¾	...		...			1¾
Length of plain pin	...		...			2	...		None			2
Diameter of ball pin	...		...			2 11/16	...		...			2⅝
Outside frame (extreme breadth)	6	4	6	4	6	5	6	8½	8	9¼	6	3¾
Length of ditto	18	3	18	2½	18	3	18	2½	20	4	18	3
Depth of frame sides		7		7		7¼		7¼		8		7¼
Thickness of ditto		4		4		4		4		4¼		4
Thickness of side plates		0⅜		0⅜		0⅜		0⅜		0⅜		0⅜
Ditto of horn plates		0⅜		0⅜		0⅜		0⅜		0½		0½
Length of driving-wheel springs	2	8	...		2	9	2	9	2	6		
Breadth of ditto		3⅞	...			3⅞		3⅝		3¼		
Number of plates		2 at 0⅜ 12 at 0¼	... ...			1 at 0⅜ 12 at 0 5/16		1 at 0⅜ 14 at 0 15/16		2 at 0⅜ 10 at 0 5/16		
Length of leading wheel springs	Ellip. 2	2	...		2	9	Ellip. 2	0	2	3		
Breadth of ditto		3	...			4		3		3¼		
Number of plates		2 at 0 5/16 11 at 0¼	... ...			1 at 0⅜ 14 at 0 5/16		1 at 0⅜ 11 at 0 5/16		2 at 0⅜ 10 at 0 5/16		
Length of trailing-wheel springs	Ellip. 2	2	...		Ellip. 2	0	Ellip. 2	0	2	3		
Breadth of ditto		3	...			3		3		3¼		
Number of plates		2 at 0 5/16 8 at 0¼	... ...			1 at 0⅜ 6 at 0 5/16		1 at 0⅜ 6 at 5 5/16		2 at 0⅜ 8 at 0 5/16		
Diameter of eccentrics	10⅝ and	12½		10⅞	1	1	1	1	1	1¾	12½ ×	11⅞
Throw of ditto		1¾		1⅛		1 13/16		1 13/16		1¾		1 9/16
Breadth of ditto (brass hoops)		1¾		1¾		2¼		2¼	Iron	1¾		1¾
Diameter of valve gear shafts		2⅛		2⅛		2⅛		2⅛		2¼		2⅛
Diameter of journals to ditto		1¾		1¾		1¾		1¾		2		1⅞
Length of journal		2½		2½		2½		2½		2¾		2¾
Length of slide levers		5		5		6		6		6½		6
Length of fork-end levers		6½	5 and	4 1/16		6		6		5¾		6
Diameter of ferrules		1⅝		1⅞		1⅞		1⅞		1⅞		2
Length of lifting levers		10	1	0	1	0	1	0	1	3	1	0
Length of reversing levers	12 and	10	1	0	12 and	10	12 and	10	1	3	1	0
Distance between motion bars		8½		7⅞		7		7¾	1	0¾		
Diameter of ball on cross-head spindle		3		3		3⅛		3⅛		3⅜		3⅛
Diameter of connecting rods in middle	...			2⅛		2⅝		2⅝		2¾		2⅝
Inside horn bars	4 ×	1	3¾ ×	1⅛	3½ ×	1¾	3¼ ×	1¾	4½ ×	1½	3¼ ×	1½
Distance from centre of crank axle to fire-box	1	6	1	6	1	6	1	6	1	5⅜	1	3
Distance from centre of crank axle to centre of leading axle	5	6	6	2	5	6	5	7	6	7	5	10½
Distance from centre of crank axle to centre of trailing axle	5	6	5	3½	5	9	5	9½	6	7	None	

In the construction of the boilers for these engines, the cylindrical parts of each are fixed to the smoke and fire-boxes, by 2½ inch angle irons round the upper, and 3 inch angle irons round the lower half of the boiler, firmly riveted with ¾ of an inch rivets. The tops of the outside fire-boxes of the engines for the North Midland, Northern and Eastern Counties, and the Great Western Railways, are worked into a dome-shaped figure, by which means the advantage is obtained of placing the regulator, with its appendages, immediately over the inside fire-box. The man-hole, being also placed in this dome, admits of a free access to the interior of the boiler.

The outside fire-boxes for the engines of the Belgium railways, having low semicircular tops, the steam domes are fixed on the cylindrical part of the boiler, and the regulators fixed to the tube-plate of the smoke-box. The inside fire-boxes are formed of copper plates of the dimensions shown; that portion of the tube-plate, necessary for the insertion of the tubes, being increased in thickness in order to increase its stability, as well as to assist in the more perfect securing of the tubes. The opening, in the front plate for the smoke-box doors, is, in all respects, sufficiently large to admit of free working room, for the removal and reinstatement of the copper tubes of the boiler, as occasion may require.

In the inside fire-boxes of the engines for the Great Western Railway, there are low hollow partitions, forming a clear water-space of four inches across the box; in the sides of this box, to which the partition is rivetted, apertures, eight, by four inches, are cut so as to allow of the free escape of steam from this division. The cylinders in the whole of the engines here enumerated are fixed in the lower part of the cavity of the smoke-box, and firmly bolted to the front and back plates, these plates being cut to receive the same. The pipes from the eduction ports (excepting in the engines for the Great Western Railway) are cast on the body of the cylinders, and extending across towards the middle, and uniting with its corresponding pipe, is strongly bolted thereto; on the upper surfaces of these pipes, flanches are cast with an horizontal plane, upon which the blast pipes are fixed. The blast pipe of copper, of a conical or pyramidal shape, formed with flanches at the bottom, is placed immediately over the junction of the pipes from the eduction ports, and firmly bolted thereto.

The pumps are fixed either directly or indirectly to the outer bars of the inside framework, as the shape and position of the parts may require; the rams of the engines for the Great Western Railway are worked immediately from the spindle of the cross-head; those of the North Midland and the Belgium engines, by an arm or lever attached to the piston-rod. The whole of the valve-gear, as well as the carriages for the cross-head guide-bars, are supported in their position by strong iron framework, technically called horn bars. These bars extend from the back plate of the smoke-box to the front plate of the outside fire-box, and are bolted to lugs fixed thereon to receive the ends of the bars. These bars also serve the purpose of staying the crank axle by means of horns, which are worked on the bars, and in which the bearings are fixed. The inner horn bars of the engines for the North Midland, the Belgium, and the North Eastern Railways, extend in a parallel direction, from the smoke-box to the extreme length of the guide-bars; and from thence obliquely in a Y-shaped form, uniting with each other, and forming, with the two outside horn bars, a third stay to the crank axle.

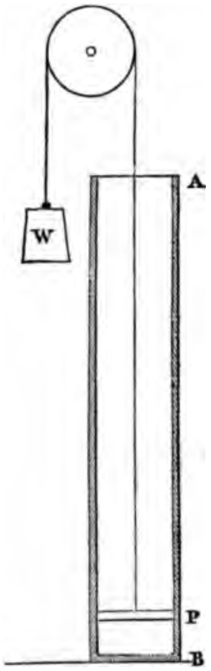
The construction of the valve-gear of the engine for the Bordeaux and La Teste Railway, differs widely in its details from the rest of the engines here noted. The eccentric bosses are placed close to each other, in the middle of the driving-wheel axle, the end of each eccentric rod being furnished with a pin on which the ferrules are placed, instead of forked ends, as have been hitherto generally adopted. On the shaft which gives motion to the valve lever is fixed a double lever, with forked ends; in the hollow of each fork a socket is formed for the reception of the pin and ferrule on the end of the eccentric rod; and of such depth as to allow the lever to have a throw, variable from 4 1/16 to 5 inches. Each of these fork-ended levers are placed in a vertical position with each other, but acting in opposite directions upon the inner end of the valve shaft. The eccentric rod ends are connected with a lever on the reversing shaft, by lifting and lowering links, which not only admit of the eccentrics being thrown in or out of gear, but also allow of a greater or less degree of travel to the slide-valve, by increasing or diminishing the throw of the fork-ended lever. The peculiar advantage of the plan thus adopted is obvious from the economy in the saving of steam, the travel of the slide being regulated so as to admit of no more steam into the cylinder than what is necessary to propel the engine at the velocity required. The link motion, latterly introduced by Mr. Stephenson, has, to a great extent, superseded the fork-ended levers, and it is a greatly preferable arrangement. The link motion is represented at page 238.

CHAPTER V.

MECHANICAL POWER OF STEAM.

Having considered, at considerable length, the general properties of steam, the connection subsisting between its temperature and its elastic force, and also the different means of generating steam, we may now proceed to consider its mechanical effect, or the power of steam to accomplish a useful purpose. The mechanical effect of steam is brought into action in three different ways, which we may call Generation, Condensation, and Expansion. The whole of these forces are brought into operation in an ordinary condensing steam engine of modern construction; nevertheless it may be useful to consider the effect of each separately. A popular exposition will suffice to illustrate our views upon this subject.

Fig. 173.



Let A B, *fig.* 173., be a tube or cylinder, and let us suppose that the area of the base is one square inch. Let it be supposed, also, that a piston P moves in the cylinder so as to be steam tight, and that there is a cubic inch of water between the bottom of the cylinder and the bottom of the piston, so that the distance of the piston from the bottom is one inch; and further, that the weight of the piston is counterbalanced by a weight W acting over the pulley, so that there is no force acting upon the piston, except the weight of the superincumbent air. Under these circumstances, the piston, being in contact with the water, and consequently all air excluded, it will be pressed down by the weight of the atmosphere. If we suppose that the pressure of the atmosphere is constant, and equal to 15 lbs. on the square inch, then the only pressure on the piston is 15 lbs.; for its area is, by hypothesis, one square inch. Let the flame of a lamp or other burning substance be now applied to the bottom of the cylinder. The temperature of the water will gradually arise, till it has attained a temperature a little above 212° Fahrenheit; and then it will begin to boil, since, by supposition, it is only subjected to a pressure of 15 lbs. per square inch. The steam will gradually force up the piston until the water has all evaporated. Now, as has been mentioned in a former part of this work, a cubic inch of water produces about 1700 cubic inches of steam at a temperature of 212; if, therefore, the tube were constructed of sufficient length, the piston would rise to about 1700 inches above the base of the cylinder. In so doing, it must obviously have raised 15 lbs. to a height of 1700 inches, or 142 feet. This represents the mechanical force of the steam generated from one cubic inch of water at temperature 212°.

It is evident that 15 lbs. raised 142 feet, is equivalent to 1 lb. raised 142 × 15 feet, or 2130 feet high, or to 142 × 15 = 2130 lbs. raised one foot high. Now, one ton is equal to 2240 lbs., which differs from 2130 only by 110; so that we may say in round numbers, that the evaporation of one cubic inch of water, under the circumstances we have supposed, generates a force which would raise one ton a foot high. The augmentation of volume which any quantity of water undergoes in passing into steam, under the pressure which we have supposed, may easily be remembered, from the accidental circumstance that water expands to about 1728 or 12^3 times its bulk in passing into steam — as if each of the particles of steam were 12 times more distant from the adjoining particle than happens in water. The facts here generally stated may be readily retained in the memory under the following forms: —

1. A cubic inch of water, evaporated under the ordinary atmospheric pressure, is converted into about a cubic foot of steam.

2. A cubic inch of water, evaporated under the atmospheric pressure, gives a mechanical force equal to what would raise about a ton weight a foot high.

We now proceed to determine the efficacy of the steam generated from a certain quantity of water, under a pressure different from that of the atmosphere. Let us suppose the piston P to be restored again to its original position, with the water below it; and, in addition to the weight of the atmosphere which before pressed it down, let us suppose another weight of 15 lbs. placed upon it, so that the water is now pressed by a force of 30 lbs. If fire were now to be applied to the cylinder, the temperature of the water would gradually rise till the boiling commenced. It is well known that the temperature would be higher in this case than the previous one. The boiling point for the ordinary atmospheric pressure is 212°, but for two atmospheres it is shown by experiment to be about 250°. When the temperature of the water had risen to 250°, the piston would then begin to ascend, and the water to be gradually converted into steam. After the water has completely evaporated, it will be found that the piston stands about 72 feet above the base of the cylinder, or a little more than half its height in the previous case. Taking it for the present, as granted, that it is exactly one half the former height, then it is obvious that the mechanical effect of the steam is the same as formerly, since it is equivalent to double the former weight raised one half the former height.

Again, suppose the piston to be restored to its original position; and suppose it to be loaded with 30 lbs; so that the water is subjected to the pressure of three atmospheres. Then applying the heat as formerly, it would be found that when the water has wholly evaporated, the piston would stand a little more than 47 feet high. So that in this case the mechanical effect is very nearly the same, since a triple weight is only raised one third the height.

In general, as the pressure on the piston is increased, the height to which the piston would be raised by the evaporation of the water will be diminished, and that very nearly in the same proportion, so that at whatever temperature steam is generated, an equal bulk of water produces very nearly an equal amount of mechanical force. In the first case, however, it is to be remarked, the pressure of the atmosphere has only been overcome, and therefore the piston with such a pressure could exert no effective power. The loss from this source becomes less as the pressure is increased, and in locomotive engines the loss from the atmospheric pressure is little more than that arising from the rare vapour in condensing engines.

In the preceding remarks we have mentioned that the height to which the piston is raised, is not exactly inversely proportional to the pressure, leaving out of the account the loss arising from the presence of the atmosphere. The difference arises from the difference in the temperatures at the commencement of the formation of steam. If the temperature at which the water is converted into steam, under the different pressures which we have supposed, continued constant, then the height to which the piston would be raised by the evaporation of the water would be diminished in precisely the same proportion as the pressure on the piston is increased. In that case the mechanical effect of a determinate quantity of water would remain exactly the same under whatever pressure the water might be boiled, supposing that there were a vacuum above the piston. But since the water boils at different temperatures, the mechanical effect of a given volume of steam varies — slightly increasing with the pressure. It would appear from this that the most advantageous development of the power of steam is obtained by using steam with a great elasticity; and this, so far as it goes, would seem to say that the most economical application of steam obtains in a high-pressure engine. It may easily be shown, however, that the superiority from this cause is very small indeed. Thus applying the received laws, it is found by a simple calculation that the temperatures being successively

$$\left.\begin{array}{r}212^\circ\\424^\circ\\636^\circ\\1060^\circ\\2112^\circ\end{array}\right\}\begin{array}{l}\text{Theory indicates that the}\\\text{mechanical effect would be}\\\text{proportional to the number.}\end{array}\left\{\begin{array}{l}1{\cdot}00\\1{\cdot}36\\1{\cdot}88\\2{\cdot}43\\8{\cdot}06\end{array}\right.$$

So that the maximum effect of a determinate quantity of heat or combustible, employed in generating steam at 424° or 15 atmospheres of pressure, is about one-third more than the maximum effect corresponding to the case in which steam is generated at 212°, or at one atmosphere of pressure. To obtain the double of this latter effect the steam must be generated at a higher temperature than 636°, that is to say, under a greater pressure than 85 atmospheres. Hence we may conclude from these results, that there can be very little advantage in respect of economy of fuel in generating steam at very high pressures. We shall explain afterwards the law according to which the variation of temperature in the water and steam modifies the mechanical effect. In the meantime, however, as the effect is very nearly constant, especially within the limits of practice, it may be useful to remember the following important practical conclusion.

"A cubic inch of water converted into steam will supply a mechanical force very nearly equal to a ton weight raised a foot high; and this force will not be subject to considerable variation, whatever be the temperature or pressure at which the water may be evaporated, provided the steam does not act expansively, and that there is a vacuum above the piston."

We have shown in page 42., formula (U), that the volume of steam generated from a unit of water, at temperature t and corresponding pressure f, is,

$$\frac{75{\cdot}67\ (459+t)}{f},$$

where t expresses the temperature on Fahrenheit's scale, and f the elastic force of steam corresponding to temperature t, as measured in inches of mercury. Hence, if P denote the whole pressure upon the water, expressed in lbs., that is to say, the load + the atmospheric pressure, then, for the mechanical effect of a cubic foot of water converted into steam at temperature t, we have P lbs. raised $75{\cdot}67\ (459+t) \div f$ feet high, or $P \times 75{\cdot}67\ (459+t) \div f$ lbs. raised one foot high. Now a height of f inches of mercury produces a pressure of $70{\cdot}75 \times f$ lbs. on a square foot; hence $P = 70{\cdot}75 \times f$. The mechanical force of the steam generated from a cubic foot of water, at temperature t, is therefore represented by

$$70{\cdot}75 \times f \times 75{\cdot}67 \times (459+t) \div f \text{ lbs.}$$

raised one foot high. By a little reduction we find, for the effect of a cubic foot of steam generated under the supposed circumstances, $5354\ (459+t)$ lbs. raised one foot high. This effect, we perceive, depends upon the temperature, and increases with it; but the increase is but small, especially within the limits of the pressures used in practice. Thus we may find what temperature steam ought to be generated at in order to produce double the mechanical effect of steam, generated from the same quantity of water, at the ordinary atmospheric pressure. It may be found, from the equation,

$$t + 459 = 2\ (459 + 212);$$

$$\text{or, } t = 459 + 2 \times 212 = 459 + 424 = 883^\circ.$$

This corresponds to an elastic force of about 1194 atmospheres, or 17910 lbs. per square inch — a pressure very much exceeding any used in practice. It is obvious, however, that this increased mechanical force is, so far as it goes, an argument in favour of the superiority of those engines which use steam of a high pressure; but, if we consider that steam at an elevated temperature is likely to lose more of its elasticity from dispersion than steam of a low pressure, and also the increased dangers and expense of high-pressure engines, we may conclude that the advantage is in favour of the other system. We may remark that, in the above estimate of the mechanical effect of steam, we have neglected to consider the reduction arising from friction, waste, dispersion, and other circumstances which in practice modify the result.

In illustrating the mechanical power of steam as brought into action by condensation, we shall use the same figure. Suppose that when the steam had raised the piston to 142 feet above the base of the cylinder, it were suddenly condensed, it is obvious that the piston would be impelled with a force equal to the pressure of the atmosphere on the piston, and through a height equal to that through which the piston had been raised by the generation of the steam. In descending it is obvious that the piston would raise a weight attached to it equal to that due to the atmospheric pressure, and through a height exactly equal to the maximum height of the piston above the base of the cylinder. If a weight were placed upon the piston in addition to the atmospheric pressure, then, as we said formerly, the piston would not rise to such a height, and consequently upon condensation the weight would not be raised so high either; but to compensate for the deficiency the weight raised would be greater, and that very nearly in the same proportion. Hence the mechanical power of the steam of a given quantity of water as developed by condensation continues very nearly constant whatever be the force at which it is generated, the difference being in favour of the greatest pressure. We see from this that the mechanical power of the steam of a given quantity of water is the same, whether it be developed by generation or by momentary condensation, and that it remains very nearly constant whatever be the temperature of the steam.

In estimating the effect of condensation, we have supposed it to be momentary and complete. It is well known, however, that in practice this can never be the case. If the steam be slowly condensed, as it would be by applying external cold, with insufficient cooling surface, the effect would be much reduced; because the moving force at any period of the stroke would be only the difference between the elastic force of the steam and the atmospheric pressure. This does not, however, cause a sensible deviation from the ratio of the power, it being proportional to the space the steam occupies.

Before leaving this we may illustrate the method of developing the mechanical force of steam in the common high-pressure engine. Suppose, as in the last case, that a loaded piston has been raised, and that, instead of the steam being condensed, that a valve has been opened which allows it to escape; then obviously the power which would have resulted from the condensation will be lost. This loss is measured by the pressure of the atmosphere acting through the height to which the piston was raised by the steam; and, as the greater the elastic force of the steam the less the height to which the piston is raised by the same weight of steam, it is obvious that the loss is smaller according as the temperature is greater. If, however, the valve aperture be too small, then the steam does not escape with the requisite rapidity, and a part of the load is applied to force it out, which is just so much of the effective force of the steam lost.

It is well known that the condensation is never complete, and therefore it may be necessary to estimate the resistance which the vapour offers. Now the resistance of the imperfectly-condensed steam acts through the whole space which it occupies in its elastic state; that is, as we have shown, through

$$\frac{75{\cdot}67\ (459+t)}{f}\text{ feet.}$$

Hence, if f_1 denote the elastic force of the vapour as measured in inches of mercury, and therefore $70{\cdot}75 f_1$ as measured in lbs. per square foot, then the mechanical effect of the uncondensed vapour is represented by

$$\frac{75{\cdot}67\ (459+t)}{f} \times 70{\cdot}75 f_1$$

lbs. raised one foot. This reduces to

$$\frac{5354\ (459+t) f_1}{f}$$

lbs. raised one foot. Hence, neglecting the waste and friction of the piston, we have for the mechanical effect of one cubic foot of water, as developed by condensation,

$$5354\ (459) + \left\{\ 1 - \frac{f_1}{f}\right\} = \frac{5354\ (459+t)\ (f - f_1)}{f}$$

lbs. raised one foot. Before leaving this, we may also estimate the loss resulting from friction of the piston. Let f_2 denote the friction of the piston, which friction we suppose constant. It is obvious that this friction operates in exactly the same manner as the uncondensed steam. The mechanical loss resulting from it will therefore be represented by

$$\frac{5354\ (459+t) f_2}{f}$$

lbs. raised one foot. Hence the mechanical effect of a cubic foot of water, as developed by condensing the corresponding quantity of steam, is represented by

$$5354\ (459+t)\left\{1 - \frac{f_1 + f_2}{f}\right\} = 5354\ (459+t)\frac{f - f_1 - f_2}{f}$$

lbs. raised one foot. These formulæ or equations have been determined on the supposition that exactly a cubic foot of water was used; but we may obviously find the mechanical effect of any quantity of water, by merely multiplying by the number of cubic feet — We may now proceed to illustrate the power of steam as developed by expansion.

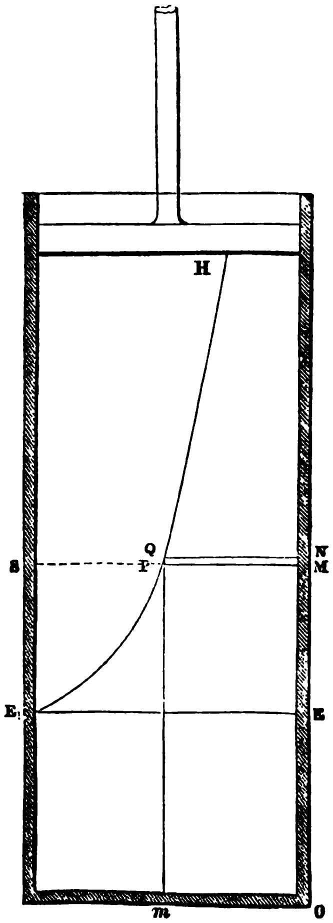
EXPANSION.

The mechanical effect of expansion is most readily determined by the principles of the Integral Calculus, and we prefer a recourse to that analysis on the present occasion. Steam, like all other gases, follows the law of Mariotte, which may be stated in the following words: — "The volume of a given quantity of gas is inversely proportional to the pressure to which it is subjected." Before this law can be applied rigorously to steam, it is necessary to suppose the temperature constant throughout the whole expansion — a supposition which, though not strictly correct, is so nearly true that we may reason upon it without material error

This law of Mariotte, it will be observed, is virtually the same as that stated at page 12., viz. that the pressure of all elastic fluids varies inversely as the spaces they are made to occupy. Thus, if a cubic foot of air or steam of the atmospheric density be compressed into the space of half a cubic foot, the pressure will be increased from 15 lbs. on the square inch to 30. It is easy, therefore, in an engine working expansively, when the initial pressure of the steam is known, and the part of the stroke at which the steam is cut off, to compute the terminal and all intermediate pressures, and the total force thus exerted during a stroke may be found approximately with sufficient nearness for practical purposes. Thus, if an engine works with steam of 25 lbs. pressure above the atmosphere, the total pressure per square inch upon the piston at the commencement of the stroke will be 25 + 15 = 40 lbs., and if the steam be cut off at one-fourth of the stroke the dense steam admitted from the boiler will, at the termination of the stroke, have expanded into four times its original bulk, and its pressure will have been diminished to 10 lbs. on each square inch of the piston, being 5 lbs. below the atmospheric pressure. The pressure within the cylinder at half-stroke, when the steam has expanded into twice its original bulk, will be 20 lbs on the square inch, and its pressure at any other point may be easily computed, as it will just vary inversely as the space occupied. The figure given at page 12., shows the method of computing the pressure of the steam at the different stages of the stroke, the pressure of the dense steam entering from the boiler being taken as unity. We shall, however, give another figure to illustrate our present observations.

If a loaded piston be raised, by the conversion of a given quantity of water into steam, to the height corresponding to the load and temperature, then, if a part of the load be removed, the steam will expand until its elastic force balances the remaining load, together with the atmospheric pressure. It is obvious that the mechanical power, thus developed, is a complete gain. Thus it may be shown that when the steam is of high elastic force, and the load is entirely removed so as to allow the steam to expand till its elastic force balances the atmosphere, its mechanical effect is doubled by the arrangement. This is not, however, the most efficacious method of applying the principle of expansion. It may be developed with greater advantage if, instead of removing the weight at once, it be removed by degrees, allowing at each time the steam to expand till its elastic force balances the remaining load. We must, however, dismissing these general considerations, now show the method of calculating the mechanical effect gained by this method of working steam engines, which is one of the most important topics of which we have to treat.

Fig. 174.



Suppose that when the piston is in the position E E_1, *fig.* 174., the water is all converted into steam, equilibrium will then be established. If now the load be gradually removed, the steam will gradually expand; and, as we said before, all the additional weight thus raised is so much mechanical power gained. The elasticity of the steam continually diminishing according to the law of Mariotte, let O E_1 represent the volume in expanding, and E E_1 the elastic force at the commencement of the expansion, and O S the volume, and P M the elastic force, after a part of the expansion: then, according to the law of Mariotte, we have

$$\mathrm{OS} : \mathrm{OE}_1 :: \mathrm{EE}_1 : \mathrm{PM};$$

or,

$$\mathrm{OM} : \mathrm{OE} :: \mathrm{EE}_1 : \mathrm{PM};$$

and therefore,

$$\mathrm{OM} \times \mathrm{PM} = \mathrm{OE} \times \mathrm{EE}_1.$$

Putting

$$\mathrm{OM} = x,\ \mathrm{PM} = y, \text{ and area } \mathrm{OE}_1 = a^2,$$

this equation becomes

$$x y = a^2.$$

Those conversant with the theory of curves will perceive that this is the equation of the equilateral hyperbola referred to its asymptotes.

In order that the piston should remain at rest in the position S M, it is necessary that the pressure upon the piston should equal the elastic force of the steam. If the load upon the piston be in the smallest degree below this, the piston will be forced up till the increased expansion has so diminished the elastic force of the steam as just to balance the diminished load. Suppose, however, that the equilibrium is established, and that the piston remains at rest in the position S M. Let so much of the weight at once be removed as to allow the piston to move up to the position Q N. Then it is obvious that the mechanical effect gained by the generation of the steam only, has the same proportion to the mechanical effect gained by this small degree of expansion, as the rectangle O E_1 has to the rectangle Q N × M N. The mechanical effect gained by removing at once the load necessary to allow the piston to take the position Q N, is smaller than what would be gained by taking the load off gradually. The loss proceeding from this cause will be less as compared with the mechanical effect gained, in proportion as N M is diminished, so that, to use the language of the Infinitesimal Calculus, if N M be infinitely small, then the loss will be nothing at all. When N M is infinitely small, then the rectangle Q N × N M is equal to the area Q N M P. Following out this reasoning, we find that if we represent the mechanical effect gained by generation, by the area O E_1, then the mechanical effect gained by the expansion from O E to O S is represented by the area E_1 P M E. It is shown by mathematical writers, that the area E_1 P M E is equal to the area OE_1 multiplied by the hyperbolic logarithm of O M ÷ O E. Hence it is not difficult to determine the effect of any given amount of expansion.

In what precedes we have endeavoured to illustrate by a geometrical figure the amount of mechanical effect gained by expansion. We have chosen this method, because a sensible representation generally makes a more vivid and lasting impression than abstract reasoning. In order, however, that our readers may be made fully master of that which is generally considered so great a puzzle to the tyro, we proceed to consider it in a somewhat different light.

Let b denote either the bulk of the steam or the height through which the piston has risen, supposing the area of the base to be one square foot, before the expansive pressure is applied, and p its force, or the load on the piston, including the atmospheric pressure; let x denote its volume after a certain amount of expansion, then we find the proper load or force from the above-mentioned law, which gives us the analogy

$$x : b :: p : \text{force after expansion to bulk } x.$$

This gives us

$$\text{force after expansion to bulk } x = \frac{p\,b}{x}.$$

Now, suppose, in accordance with the spirit of the infinitesimal calculus, that the force continues constant through a very small expansion denoted by $d\,x$; then the mechanical effect gained by this expansion will be represented by $\frac{p\,b}{x}\,d\,x$. If we could sum these from $x = b$ to $x = x$, we would find the mechanical effect gained by the corresponding expansion; it is this summation which the integral calculus effects. Adopting the notation of the integral calculus we obtain, for the mechanical effect of the expansion from volume b to volume x, the expression

$$\int_b^x \frac{p\,b\,d\,x}{x} = p\,b\,\log_e \frac{x}{b}.$$

In this expression $\log_e \frac{x}{b}$ denotes the logarithm of the quantity $x \div b$ in the system whose base is $e = 2{\cdot}7182818$; that is, the common hyperbolic logarithms, a table of which we have given at page 25. We may express this result in a form more suited for practical application. Suppose the volume of steam before expansion to be to the volume after expansion in the proportion of 1 to n; in other words let $x = n\,b$, then remembering that, as we have shown previously,

$$p\,b = 5354\,(459 + t)$$

we find for the mechanical effect of the expansion E pounds raised one foot high, where

$$E = 5354\ (459 + t) \log_e n.$$

We learn from this that not only is mechanical effect gained by using expansion, but that there is no limit to this gain, if steam be supposed to be infinitely expansible, other than the inconveniences arising from the too extensive application of the principle in practice. The above formula will be useful for determining the amount of mechanical effect gained by cutting off the steam at different parts of the stroke. To facilitate the application of this formula we shall just state the values of n when the steam is cut off at different parts of the stroke. If the steam be cut off at $\frac{1}{2}$ stroke, then $n = 2$; if the steam be cut off at $\frac{1}{3}$ stroke, then $n = 3$; and generally, if steam be cut off at $\frac{1}{m}$ stroke; then $n = m$, or more generally still, if the steam be cut off at $\frac{p}{q}$ stroke, then $n = \frac{q}{p}$.

The mechanical effect of a cubic foot of water converted into steam, and then allowed to expand to n times its volume, is therefore represented by

$$5354\ (459 + t)\ \{1 + \log_e n\}$$

lbs. raised one foot high.

In order to find how much the effect of the steam has been multiplied by the use of the expansive principle, it is only necessary to divide this result by the result when expansion is not used $\left(5354 \times (459 + t)\right)$. The quotient is $1 + \log_e n$. By using the table of hyperbolic logarithms, which we have given at page 25., we can very easily find the effect of the expansion. To illustrate the method, suppose it were required to find how much the effect of the steam was multiplied by cutting it off at $\frac{3}{4}$ stroke. In this case $n = \frac{4}{3} =$ 1·3. The hyperbolic logarithm of this number is ·3. Hence the effect of the steam is multiplied 1·3 times. As another example, suppose the steam was cut off at $\frac{2}{15}$ stroke. In this case, $n = \frac{15}{2} = 7{\cdot}5$. The hyperbolic logarithm of this number is 2·015. Hence the effect of the steam is multiplied 3·015 times.

We may now consider the results of the expansive principle when used in combination with condensation. It is obvious that when the expansive principle is applied, that is, if the steam be to expand during its action on the piston, an increased length of cylinder is necessary. The friction of the piston, and the resistance of the uncondensed vapour, therefore act through a greater space; a reduction of the gross effect will therefore follow from this cause which, so far as we have gone, we have totally overlooked. The total mechanical effect of a cubic foot of water converted into steam, using expansion and condensation, and making allowance for waste for friction of the piston, &c., and for resistance of the uncondensed steam, will be represented by

$$5354\ (459 + t) \left\{1 + \log_e n - \frac{n\,(f_1 + f_2)}{f}\right\} w$$

lbs. raised one foot high.

Since the mechanical effect increases with the extent of expansion, and the mechanical loss resulting from the friction of the piston and the resistance of the imperfectly condensed steam also increase with the expansion, it is obvious that there must be a certain expansion which gives the maximum effect. This will be found by rendering the preceding quantity a maximum, which obtains when $\log_e n - \frac{n\,(f_1 + f_2)}{f}$ is a maximum. It may be shown by the ordinary rules for maxima and minima that this obtains when

$$n = \frac{f}{f_1 + f_2}.$$

Consequently, inserting this value of n, we shall have for the maximum effect of the steam generated from a cubic foot of water

$$5354\ (459 + t) \times \log_e \frac{f}{f_1 + f_2} \times w$$

lbs. raised one foot.

Supposing that in well constructed engines there is a loss of $\frac{1}{10}$ of the steam by the waste spaces and otherwise; then $w = 1 - \frac{1}{10} = {\cdot}9$, and we have for the maximum mechanical effect of the steam of a cubic foot of water in the best constructed engines

$$4819\ (459 + t) \times \log_e \frac{f}{f_1 + f_2}$$

lbs. raised one foot high.

If we take the same proportion of waste, we find for the maximum effect of steam when not used expansively

$$4819\ (459 + t) \left\{1 - \frac{f_1 + f_2}{f}\right\}$$

lbs. raised one foot high. Subtracting this from the former, we obtain for the maximum gain by expansion

$$4819\ (459 + t) \left\{\log_e \frac{f}{f_1 + f_2} + \frac{f_1 + f_2}{f} - 1\right\}$$

lbs. raised one foot high.

The equations show us the limits of steam power. It is not to be supposed that in actual practice such results will be commonly obtained. The formulas show, however, that the mechanical effect of the steam of a given quantity of water increases as the temperature at which the steam is generated; and as the same quantity of fuel converts the same quantity of water into steam, whatever be the pressure, at least if the doctrine be conceded that the sum of the latent and sensible heats of common steam form nearly a constant quantity, it would seem that the most advantageous use of steam is obtained by generating it at high temperatures. It may be observed, however, that within the limits of practice, the advantage gained by high pressure steam used without expansion is very small, so small indeed as not to compensate for the increased dangers attendant upon the use of steam of great elastic force.

We may here give a table of some of the properties of steam, and of its mechanical effects at different pressures. This table may help to solve many problems respecting the mechanical effect of steam, usually requiring much laborious calculation.

Pressures.		Temperature in degrees Fahren.	Weight of a Cubic Foot Steam.	Velocity of Exit.	Mechanical Effect, in Horse Power, of 1 Lb. of Steam.							
					Without Condensation. Expansion.				Condensation. Expansion.			
Atmosphere.	Lbs. per Sq.Inch.				0	½	⅓	¼	0	½	⅓	¼
1·00	14·70	212·00	0·0364	0	0	32·4	95·2	170·5	91·3	150·1	178·6	194·6
1·25	18·38	223·88	0·0440	873	21·5	10·1	32·3	87·4	95·9	158·7	190·6	209·9
1·50	22·05	234·32	0·0529	1135	36·4	39·3	10·8	30·6	99·3	165·2	199·6	221·1
1·75	25·72	242·78	0·0609	1295	47·4	60·8	42·5	11·1	102·0	170·0	206·2	229·5
2·00	29·40	250·79	0·0688	1407	55·9	77·5	67·0	43·2	104·3	174·2	212·0	236·5
2·25	33·08	257·90	0·0766	1491	62·8	50·9	86·5	68·8	106·2	177·7	216·7	242·4
2·50	36·75	263·93	0·0344	1556	68·4	101·8	102·4	89·6	107·7	180·5	220·5	247·1
2·75	40·42	269·87	0·0921	1608	73·1	111·0	115·8	107·1	109·3	183·2	224·2	251·6
3·00	44·10	275·00	0·0998	1652	71·1	118·8	127·1	121·9	110·5	185·4	227·7	255·2
3·35	47·78	279·86	0·1073	1690	80·7	125·6	137·1	136·7	111·7	187·6	230·0	258·7
3·50	51·45	284·63	0·1148	1722	83·8	131·5	145·6	145·8	112·7	189·4	232·4	261·6
3·75	55·12	288·66	0·1225	1750	86·5	136·8	153·2	155·6	113·7	190·1	234·7	264·4
4·00	58·18	292·91	0·1298	1774	89·0	141·5	160·	164·5	114·6	192·8	236·9	267·0
4·50	66·15	300·27	0·1445	1816	93·2	149·8	171·5	179·4	116·2	195·6	240·5	271·4
5·00	73·50	307·94	0·1590	1850	96·8	156·5	181·6	192·0	117·7	198·3	244·1	275·6
6·00	88·20	320·00	0·1878	1904	102·5	167·2	196·5	211·4	120·2	202·6	249·7	282·2
7·00	102·90	331·56	0·2159	1945	107·0	175·6	208·4	226·5	122·4	206·4	254·6	288·1
8·00	117·60	340·83	0·2436	1978	110·6	182·4	217·9	238·4	124·3	209	258·8	292·1
9·00	132·30	351·32	0·2708	2006	113·7	188·2	225·9	248·5	126·0	212	262·7	293·6
10·00	147·00	359·60	0·2977	2029	116·3	193·0	232·5	256·7	127·5	215	266·0	301·4
12·50	183·75	377·42	0·3642	2074	121·5	202·5	245·5	273·0	130·7	220	272·9	309·5
15·00	220·50	392·90	0·4288	2109	125·7	210·0	255·6	285·4	133·4	225	278·9	316·4
17·50	257·25	406·40	0·4924	2136	129·0	216·0	263·6	295·2	135·7	229	283·9	322·2
20	294·00	418·56	0·5549	2159	131·8	221·0	270·3	305·3	137·8	233	288·3	327·2
25	367·50	429·34	0·6775	2196	136·3	229·1	281·0	316·2	141·2	238	295·7	335·8
30	441·00	457·16	0·7970	2226	140·0	235·6	289·5	326·4	144·2	244	302·0	343·1

It is quite clear that although there is no theoretical limit to the benefit derivable from expansion, there must be a limit in practice, arising from the friction incidental to the use of very large cylinders, the magnitude of the deduction due to uncondensed vapour when the steam is of a very low pressure, and other circumstances which it is needless to relate. It is clear, too, that while the efficiency of the steam is increased by expansive action, the efficiency of the engine is diminished, unless the pressure of the steam or the speed of the piston be increased correspondingly; and that an engine of any given size will not exert the same power if made to operate expansively without any other alteration that would have been realised if the engine had been worked with the full pressure of the steam. In the Cornish engines, which work with steam of 40 lbs on the inch, the steam is cut off at one twelfth of the stroke; but if the steam were cut off at one twelfth of the stroke in engines employing a very low pressure, it would probably be found that there would be a loss rather than a gain from carrying the expansion so far, as the benefit might be more than neutralised by the friction incidental to the use of so large a cylinder as would be necessary to accomplish this expansion, and unless the vacuum were a very good one there would be but little difference between the pressure of the steam at the end of the stroke and the pressure of the vapour in the condenser, so that the urging force might not at that point be sufficient to overcome the friction. In practice, therefore, in particular cases, expansion may be carried too far, though theoretically the amount of the benefit increases with the amount of the expansion.

The preceding investigations, coupled with the remarks on the subject of expansion given in pages 12 and 94., will probably make the question tolerably plain to most readers; but we must here introduce a simple practical rule to enable those who may not be familiar with mathematical symbols to determine the amount of benefit due to any particular measure of expansion. When expansion is performed by an expansion valve, it is an easy thing to ascertain at what point of the stroke the valve is shut by the cam, and where expansion is performed by the slide valve the amount of expansion is easily determinable by the rules or tables given at pages 89 and 90, when the lap and stroke of the valve are known.

To find the Increase of Efficiency arising from working Steam expansively.

RULE.—*Divide the total length of the stroke by the distance (which call* 1) *through which the piston moves before the steam is cut off. The Neperian logarithm of the whole stroke expressed in terms of the part of the stroke performed with the full pressure of steam, represents the increase of efficiency due to expansion.*

Example I. Suppose that the pressure of the steam working an engine is 45 lbs. on the square inch above the atmosphere, and that the steam is cut off at one fourth of the stroke; what is the increase of efficiency due to this measure of expansion?

If one fourth be reckoned as 1, then four fourths must be taken as 4, and by reference to page 25. the Neperian or hyperbolic logarithm of 4 will be found to be 1·386, which is the increase of efficiency. The total efficiency of the quantity of steam expended during a stroke, therefore, which without expansion would have been 1, becomes 2·386 when expanded into 4 times its bulk, or, in round numbers, 2·4, as stated at page 12.

Example II. Let the pressure of the steam be the same as in the last example, and let the steam be cut off at half-stroke: what, then, is the increase of efficiency?

Here half the stroke is to be reckoned as 1, and the whole stroke has therefore to be reckoned as 2. The hyperbolic logarithm of 2 is ·693, which is the increase of efficiency, and the total efficiency of the stroke is 1·693, or 1·7 as stated at page 12.

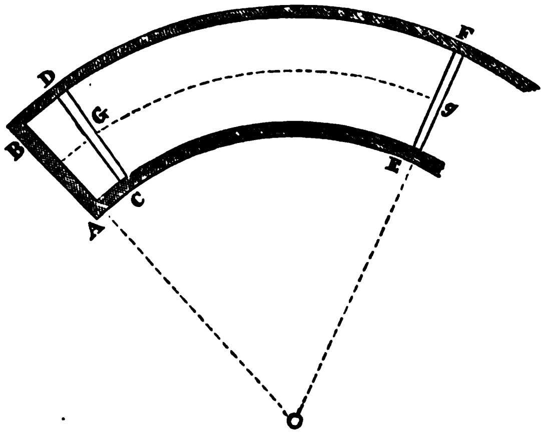
We may here give a table to illustrate the mechanical effect of steam under varying circumstances. The table shows the mechanical effect of the steam generated from a cubic inch of water. Our formula gives the effect of a cubic foot of water; but it can be modified to give the effect of the steam of a cubic inch by dividing by 1728. In this manner we find, for the mechanical effect of the steam of a cubic inch of water, about 3 $(459 + t)$ lbs. raised one foot high. The table shows that the mechanical effect increases with the temperature. The increase is very rapid for temperatures below 212°; but for temperatures above this the increase is less; and for the temperatures used in practice we may consider, without any material error, the mechanical effect as constant.

Total pressure in lbs. per Square Inch.	Corresponding Temperature.	Volume of Steam compared with Water.	Mechanical effect of Cubic Inch of Water.	Total pressure in lbs. per Square Inch.	Corresponding Temperature.	Volume of Steam compared with Water.	Mechanical effect of Cubic Inch of Water.
1	103	20,868	1739	51	284	544	2312
2	126	10,874	1812	52	286	534	2316
3	141	7437	1859	53	287	525	2320
4	152	5685	1895	54	288	516	2324
5	161	4617	1924	55	289	508	2327
6	169	3897	1948	56	290½	500	2331
7	176	3376	1969	57	292	492	2335
8	182	2983	1989	58	293	484	2339
9	187	2674	2006	59	294	477	2343
10	192	2426	2022	60	296	470	2347
11	197	2221	2036	61	297	463	2351
12	201	2050	2050	62	298	456	2355
13	205	1904	2063	63	299	449	2359
14	209	1778	2074	64	300	443	2362
15	213	1669	2086	65	301	437	2365
16	216	1573	2097	66	302	431	2369
17	220	1488	2107	67	303	425	2372
18	223	1411	2117	68	304	419	2375
19	226	1343	2126	69	305	414	2378
20	228	1281	2135	70	306	408	2382
21	231	1225	2144	71	307	403	2385
22	234	1174	2152	72	308	398	2388
23	236	1127	2160	73	309	393	2391
24	239	1084	2168	74	310	388	2394
25	241	1044	2175	75	311	383	2397
26	243	1007	2182	76	312	379	2400
27	245	973	2189	77	313	374	2403
28	248	941	2196	78	314	370	2405
29	250	911	2202	79	315	366	2408
30	252	883	2209	80	316	362	2411
31	254	857	2215	81	317	358	2414
32	255	833	2221	82	318	354	2417
33	257	810	2226	83	318	350	2419
34	259	788	2232	84	319	346	2422
35	261	767	2238	85	320	342	2425
36	263	748	2243	86	321	339	2427
37	264	729	2248	87	322	335	2430
38	266	712	2253	88	323	332	2432
39	267	695	2259	89	323	328	2435
40	269	679	2264	90	324	325	2438
41	271	664	2268	91	325	322	2440
42	272	649	2273	92	326	319	2443
43	274	635	2278	93	327	316	2445
44	275	622	2282	94	327	313	2448
45	276	610	2287	95	328	310	2450
46	278	598	2291	96	329	307	2453
47	279	586	2296	97	330	304	2455
48	280	575	2300	98	330	301	2457
49	282	564	2304	99	331	298	2460
50	283	554	2308	100	332	295	2462

Before leaving this part of our subject, it may be useful to examine the mechanical effect of steam as employed to produce rotatory motion. We think it the more advisable to pursue this investigation, on account of the misconception that has prevailed upon the subject. In a great majority of the cases in which steam is employed, it is for the purpose of producing rotatory motion. In the common reciprocating engine the rotatory motion is produced by the agency of the crank. Upon a cursory examination of the principle of the crank, it would seem that it absorbs a great amount of the mechanical effect of the steam, a great part of the effect of the steam being employed to produce a useless pressure. Engineers of some celebrity have fallen into this error, imagining that in this case the machinery absorbed power instead of merely transmitting it; and thus controverting that great principle upon which we may consider mechanical science as founded, viz. that machinery or solid matter in general may obey force and modify it, but it can never either create or consume it. Many engineers, however, who were perfectly aware of the generality of the law we have mentioned, and perceived that it subsisted in the case of the crank, have imagined that a theoretical benefit would be gained if the rotatory motion were produced by the direct action of steam, instead of being obtained by the intervention of so many moving parts for converting the rectilineal motion produced by steam into a rotatory one; but it is not difficult to show that power is neither lost by the crank nor by the direct action of the steam in a rotatory engine, and that though a good rotatory engine may be a desideratum for specific applications, yet that no theoretical gain or loss is attributable to its employment. Starting from the great law we have mentioned of the inactivity of matter, we may conclude at once that, in theory, the power of the steam, as developed by that class of rotatory engines which use the revolving piston, is exactly the same as in the common engine possessing the cylinder, for the revolving piston in the rotatory engine is merely a piece of matter, and, as such, cannot absorb power more than the piston in the common engine, on the supposition that the loss resulting from friction is the same in both. We are surprised that Tredgold has lost sight of this very simple and general principle, but we shall here show that his conclusion that there is always a loss of power in the rotatory engine, extending in some cases to the amount of ¼ the power, is fallacious.

Let *fig.* 175. represent a part of the cylinder used in that class of rotatory engines which use revolving pistons. Suppose, for the sake of simplicity, that the area at A B is one square foot, and that A B D C contains a cubic foot of water. Suppose, also, that D C is loaded with a weight such, that together with the atmospheric pressure, the force upon D C will be $70·75 f$ lbs. Let the water now be heated, it will begin to boil whenever it attains a temperature t corresponding to f; and as we have shown formerly, the volume will be $75·67\ (459 + t) \div f$ cubic feet. Let A B F E represent the volume it now occupies. The content of this volume is A B × G g. Hence $Gg = 75·67\ (459 + t) \div f$ lineal feet; the mechanical power of the steam as developed in this cylinder is therefore represented by $70·75 f$ raised $75·67\ (459 + t) \div f$ lineal feet; or $5354\ (459 + t)$ lbs. raised one foot, exactly the same power as in the common cylinder. In fact, rotatory engines with revolving pistons are, theoretically speaking, as well calculated to abstract the mechanical force of the steam as the common reciprocating engines; and would be likely to furnish a successful competition were it not for the great increase of friction. This has hitherto operated as a barrier to their application, and is likely still to do so in the case of statical engines. The common reciprocating engine possesses great superiority over its competitor in simplicity of parts, in facility of construction, precision and uniformity of action, and durability and economy in use; and this superiority is not counterbalanced by any real advantage in the rotatory engine as hitherto contrived. Much talent has been wasted in unsuccessful attempts to remove the great disadvantages under which the rotatory engine labours; and, although the formation of a good rotatory engine would no doubt be a desideratum, we have no expectation such an engine will be found that will operate on a statical principle with success.

Fig. 175.



In the whole of the preceding remarks it is to be borne in mind that a deduction is to be made in the case of high pressure engines, for the pressure of the atmosphere; and the doctrine that about the same mechanical power is exerted by the same weight of steam operating without expansion, or with the same degree of expansion, is only true when the pressure of the atmosphere is subtracted, as in the case of a condensing engine, and where the friction is left out of the account. Engines may be divided into two great classes or genera, depending on the circumstance of condensation being used or not. Engines in which condensation is used, are termed condensing engines; while engines in which condensation is not used are called non-condensing engines. These two classes are sometimes respectively called low pressure engines, and high pressure engines. In the ordinary engine, constructed on Watt's principle, the safety valve is seldom loaded with more than 5 lbs. on the square inch. For this reason a condensing engine is often termed a low pressure engine; while, if the condensing apparatus be dispensed with, the piston will always be resisted by a force equal to the atmospheric pressure, and the only part of the steam pressure which will be available as a moving power, is that part by which it exceeds the pressure of the atmosphere. Hence, in engines which do not work by condensation, steam of a much higher pressure than that of the atmosphere is necessary; and for this reason non-condensing engines are called high pressure engines. The terms high pressure engines, and low pressure engines may be very much objected to, as calculated to mislead; for, although in general the steam used in a non-condensing engine has a greater elastic force than the steam used in a condensing engine, it is by no means necessary that the steam used in condensing engine should be at a low pressure. Nor indeed is it always so. In the condensing engines constructed on the principle of Watt, the steam is sometimes generated at a pressure 5 lbs. per square inch greater than the atmospheric pressure, and in Woolf's engines the steam is produced under a pressure of 40 lbs. on the square inch, although still it is condensed. Most of the efficacy of the Cornish engines is traceable to the use of high pressure steam used expansively; and in practice the use of steam of a considerable pressure is expedient, as it enables the steam to work very expansively without involving the use of engines of great cost and inconvenient dimensions, which, moreover, would lose power in friction, and by the resistance due to the uncondensed vapour.

Of all the expedients for economising fuel in steam engines, expansion is that which has been attended with most success; yet various other resources have been tried in the application of the steam, or in the substitution for steam of some other elastic fluid. We have already given at page 93 an investigation of the effect of surcharging steam with heat, by which it appears that there is a slight economy attainable thereby. The boiling point of alcohol and various other liquids being lower than that of water, many persons have supposed that a material economy would be realized by the use of their vapours in working an engine, especially as many of them were found to be evaporated with a less expenditure of heat. But it appears that there is no real economy arising from the use of those liquids, as the volumes of their respective vapours are less in the proportion of the smallness of the supply of fuel requisite for their evaporation. This boiling point of water being 212°, the boiling point of alcohol is 173°, of sulphuret of carbon 116°, and of sulphuric ether 104°; but whereas the volume of the vapour of sulphuric ether at the boiling point is only 220 times greater than the volume of the liquid from which it was generated, of sulphuret of carbon 440 times, and of alcohol 476 times, the bulk of steam is 1728 times greater than that of the water out of which it was formed, and the larger volume fully compensates for the larger quantity of fuel requisite for its evaporation. Sir Humphrey Davy, many years ago, anticipated from the use of liquid carbonic acid, and other liquefied gases, an important economy of fuel; but though the vapours of those liquids exert a great pressure, with a slight addition to the temperature, they operate only through a small space, and if the fire were to be applied to them there would probably be no economy. But an economy may be realised by heating those gases by the waste water or the condensing steam.

On the relation between the length of the stroke and the diameter of the cylinder.

As long as the steam is in the cylinder producing the required power, it is losing so much of its temperature, and, consequently, its elastic force, by dispersion. The loss proceeding from this cause will obviously increase with the surface of the cylinder, which is exposed to the external air. Hence, the best proportions for avoiding this loss may be found by solving the problem—"Required the cylinder which, having a given capacity, has, at the same time, the least surface." Tredgold considering that the concave surface is only brought gradually into contact with the steam, and therefore, as may be shown, producing only the same effect as half the same surface continually in contact, finds the best proportion by solving the problem—"Required the cylinder of a given capacity, such that the areas of its two ends, together with one half the surface of its sides, may be a minimum." The proportion given by the solution of this problem is the length of the stroke to be equal to twice the diameter of the cylinder. Hence, according to Tredgold, the cylinder ought, where it is possible, to have this proportion. It is plain, however, that although the steam is not always in contact with the surface, still a continual loss is incurred from dispersion, inasmuch as the cylinder should be as hot as the steam. The proportion may therefore be found by solving the first problem. This problem may be solved by the ordinary rules for maxima and minima, as follows:—

Let length of stroke $= l$
Diameter of cylinder $= d$
Constant capacity of cylinder $= a^3$

Then, to be made a minimum, $u = 2 \times$ (area of one of the ends) + concave surface, or

$$u = \tfrac{1}{2} \pi d^2 + \pi d l,$$

And the quantities d and l, are connected by the equation

$$\pi d^2 l = 4a^3:$$

Hence, to be rendered a minimum, we have

$$u = \tfrac{1}{2} \pi d^2 + \frac{4a^3}{d}.$$

This, by differentiation, and putting $d.u \div d.d = o$, may be shown to be a minimum when $\pi d^3 = 4a^3$. Comparing this with a previous equation, we learn that the best proportion for the cylinder is when $l = d$, that is to say, when the length is equal to the diameter. It ought to be remembered that this result is derived only from one consideration, viz. the least loss by dispersion. In particular cases, other considerations must be introduced; but, as far as the loss of heat by radiation from the cylinder is concerned, the best proportion for an engine is to make the stroke equal to the diameter. In our solution we have omitted the consideration that the force of the piston is proportional to the square of the diameter, but the friction of the piston is proportional to the diameter only. The difference resulting from this omission, however, is so very small, in ordinary proportions, that it would very little affect the answer, and may safely be neglected. We may state that the difference, so far as it goes, indicates that the diameter of the cylinder ought to be a little greater than one half the length.

THEORY OF THE CRANK.

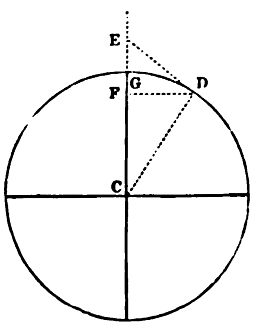
We have already given the history of the first application of the crank to the steam-engine. Since its first introduction, it has continued to be the only mechanism in practical use, for converting the reciprocating motion of the steam piston into a rotatory motion, and for this purpose it possesses great advantages in its simplicity and cheapness of construction. Besides which, great benefit is derived from its causing the motion of the piston, and other reciprocating parts of the engine, to be stopped and reversed gradually, and not by sudden jerks, and also with great exactness at the proper place, so as to obviate the necessity of much clearance in the cylinder. So great is the advantage derived from the regulating powers of the crank, that it is frequently used for the sake of these alone, where the reciprocating motion only of the piston is required, such as in pumping, &c. The eminent simplicity of the crank, in its practical application, extends even to the theory of its action, so as to obviate the necessity of our devoting very much space to its consideration; yet, strange to say, in spite of this simplicity, and its universal use, it has been the subject of a very prevalent misconception among unlearned mechanics. This has arisen from the circumstance, that, when the crank is at the top, or bottom of its revolution—turning the centre as it is called—the pressure on the piston produces no rotatory force whatever in the crank, and even when the crank has left these two positions, it is only at the two points at right angles to these, that the rotatory action is at a maximum, while over the rest of the stroke it varies between the maximum and nothing. Yet, while the rotatory or useful action is thus variable, the pressure on the piston is uniform; and hence a superficial observer, or one little used to the consideration of any mechanical problem, beyond the range of the "mechanical powers," is, naturally enough, led to infer, that the diminution of rotatory power at other parts of the stroke, is all so much loss, and that, through the action of the crank, a large proportion of the power of the steam is dissipated, and prevented from producing any useful result. Most of our readers, we presume, are aware that this conclusion is erroneous; but, as some who know that such is the fact, may have given little attention to the reason of it, it may be well to bestow a little consideration on the subject. The fallacy that we have described is founded almost entirely on a confusion of ideas and language relative to *power* and *pressure*. These two words are too apt to be used as synonymous, although they express two very different things. Pressure alone is not power, and cannot produce power without motion. We might, for example, have the full steam pressure exerted on a piston for hours, but, if the engine is from any cause prevented from moving, no *power* is produced, and neither is any steam expended. Power, in fact, is measured and represented by pressure multiplied by the space over which the pressure moves. Thus, a weight or pressure of 10 lbs. moving over 1 foot, gives a power expressed by $10 \times 1 = 10$; and a weight of 5 lbs. falling 2 feet, gives a power of $5 \times 2 = 10$; or, the same as the last. In other words, the pressure of 10 lbs. produces no more power than that of 5 lbs., because it moves over only one half the space. These considerations applied to the crank will readily clear up every difficulty.

The pressure on the piston is the same at all parts of the stroke; but the speed with which it moves is variable, being greatest at half stroke, and least at the beginning and end of the stroke, while the motion of the crank is uniform. As the speed of the piston is variable, and the *power* is represented by the pressure multiplied by the space passed over, the power given out by the piston every instant, must, like the speed, vary constantly, between the maximum at half stroke, and nothing at the extremities of the stroke. When therefore we find that the rotatory power of the crank varies in the same way, this arises, not from part of the power of the piston being dissipated, but from the power of the piston itself alternately increasing and diminishing as its speed varies.

It is a well known first principle in theoretical mechanics, that (excluding the consideration of friction) no mechanical contrivance can either increase or diminish power, and, as a necessary consequence, that the pressure on every moving part of a machine *in the direction of its motion*, is inversely as the space it moves over. During one revolution of the crank, the crank-pin describes the circumference of a circle, twice the diameter of which, is equal to the space moved over by the piston in the same time; hence, according to the principle just laid down, the average pressure on the crank-pin in the direction of its motion, is equal to the pressure on the piston, multiplied by twice the diameter, and divided by the circumference, of a circle, that is, it is equal to the pressure on the piston multiplied by $\frac{2}{3{\cdot}1416} = {\cdot}6366$.

Independently, however, of the general law of virtual velocities, as it is called, which we have just been applying, it is very easy to show that the power given out by the crank is equal to that communicated from the piston.

Fig. 176.



Let C D represent the crank, and C E the direction of the connecting rod, then the pressure communicated to the crank-pin D, by the connecting rod, may be supposed to be represented by the line E C, and to be resolved into two pressures, one represented by the tangent D E, and tending to produce rotatory motion, the other represented by the line D C, and producing pressure on the bearing of the crank-shaft. Draw D F perpendicular to E C, and, as the triangle C E D is similar to the triangle C F D, we may suppose the whole pressure of the connecting rod to be represented by the line C D, the pressure on the bearing, by the line F C, and the pressure tending to produce rotation, by the line F D. In other words, we have, the pressure on the piston = radius; and the pressure tending to produce rotation = sin. angle F C D × radius.

Let the angle F C D = x, and suppose the crank to move over a *very small* angle represented by $d x$; then the space moved over by the crank-pin would be = radius × $d x$; and it is shown by writers on the differential calculus, that the space passed over by the piston in the same time is equal to rad. × sin. $x \times d x$.

The pressure on the piston is constant, and represented by rad.; the power exerted by the piston, while the crank moves over this small arc $d x$, must, therefore, be equal to rad.^{2} × sin. $x \times d x$.

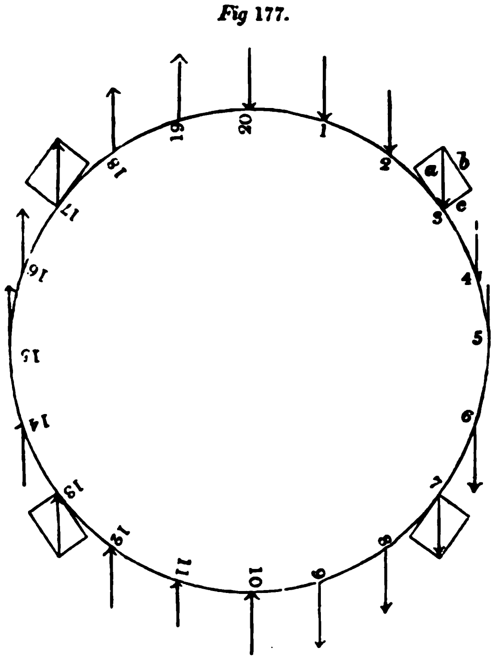
We have seen above that the pressure tending to produce rotation in the crank, is equal to sin. F C D × rad., or, sin. x × rad., and therefore the power exerted by the crank while the crank-pin moves over the space $d x$ × rad., must be equal to sin. x × rad. × $d x$ × rad., or rad.^{2} × sin. $x \times d x$.

This is the same as the expression that represents the power produced by the piston in the same time; and, as what is the same at every instant must be the same in the aggregate, it follows, that the whole power produced by the piston is equal to the whole power given out by the crank.

In what precedes, we have been obliged, on one occasion, to refer to the principles of the differential calculus, and without them, the rigid proof of the conclusion that we have arrived at would be very tedious; but for the sake of those who are not familiar with this department of mathematics, we may illustrate the proposition and approximate to the correct conclusion in a very simple and popular manner.

Thus, let *fig.* 177. represent the circle which the crank-pin describes. Divide it into 20 equal parts. Suppose the connecting rod to remain always in a parallel direction, viz., in the direction of the arrows, and the constant pressure in it to be 100. Then the pressure producing rotation, and in the direction of a tangent, at any point of the circle, will, as we have already explained, be equal to 100 × sine of the angle, described since the crank turned the centre. From this we get the following table:—

Fig 177.



Points in the Figure.		Pressure in Direction of Revolution.
At 0 and	at 20	100 × sin. 0° = 0·00
1	19	100 × sin. 18° = 30·90
2	18	100 × sin. 36° = 58·78
3	17	100 × sin. 54° = 80·90
4	16	100 × sin. 72° = 95·11
5	15	100 × sin. 90° = 100·00
6	14	100 × sin. 108° = 95·11
7	13	100 × sin. 126° = 80·90
8	12	100 × sin. 144° = 58·78
9	11	100 × sin. 162° = 30·90
10	10	100 × sin. 180° = 0·00
		Mean pressure 63·11

The circumference of the circle described by the crank-pin to the diameter 1, is 3·1416, and therefore the power given out by the crank during one revolution is expressed by 3·1416 × 63·11 = 198·266.

During the same time the piston has travelled over twice the diameter of the circle; and as the pressure is constant at 100, the power produced by the piston is expressed by 2 × 100 = 200.

This is very nearly the same as what we have got for the power of the crank; and if we were to take more divisions in the circle, so as to get the mean pressure of rotation more accurately, we would find the power of the crank approach more nearly to that of the piston, and it would approach nearer still, if we made the divisions yet more numerous; thus shewing that the final very small difference is caused by the inaccuracy of our method of approximation alone, and that the things themselves are perfectly equal.

We have hitherto, for the sake of simplifying the theory of the crank, omitted the consideration of the friction produced, while it is working, in the crank-axle and crank-pin; but we may appropriately conclude this subject by a few observations on this point.

The pressure on the crank-axle and crank-pin, derived from the connecting rod, must always be each equal to the pressure transmitted from the piston; and the frictional resistance is a certain proportional part of this pressure, the exact proportion depending on the kind of surfaces, the lubricating material, &c. We shall assume that the friction is $\frac{1}{10}$ of the whole pressure, which is rather too much; but as our present object is rather illustration than exact calculation, this will answer our purpose.

The resistance to motion arising from this source is uniform at all parts of the stroke; and as at two points (viz. the top and bottom) of each stroke the rotatory energy of the piston vanishes, there must be two points at which this rotatory energy just equals the friction. To find these let

d = diameter of crank-axle.
d' = diameter of crank-pin.

s = length of stroke.

p = pressure transmitted from the piston through the connecting rod.

x = angle described by the crank, between the top or bottom of the stroke, and the point where the rotatory action of the piston on the crank just balances the resistance from friction.

From what has been already said, it appears, that the rotatory action of the steam at this point is equal to $p \times \sin. x$, and that the friction is equal to $\frac{1}{10} p$. But the rotatory pressure of the steam acts with a leverage equal to the length of the crank, while the frictional resistance acts with a leverage equal to the combined radii of the crank-axle and crank-pin.

That, therefore, these two forces may be balanced, we must have

$$p \times \sin.\ x \times s = \tfrac{1}{10} p \times (d + d'),$$

$$\therefore \sin.\ x = \frac{\frac{1}{10}(d+d')}{s} = \frac{d+d'}{10s} \qquad \text{(A.)}$$

In an ordinary engine, where we may suppose $d + d' = \frac{1}{6} s$, this would give $\sin. x = \frac{1}{60} = {\cdot}017$, or, $x = 0^\circ\ 59'$.

At this point of the revolution, the pressure on the piston will be just able to overcome the friction of the bearings. It is evident from the formula that the smaller the diameters of the crank-axle and crank-pin are in proportion to the length of stroke, the sooner will the steam pressure be able to overcome the friction, after the crank passes the centre; and as the strength of the axle is in proportion to the cube of its diameter, while the leverage of the crank is directly as the length of the stroke, it is clear that the friction of the bearings must be more detrimental in a short than a long stroked engine.

The well known and convenient contrivance called an eccentric, is just a crank with a short radius, and a very large crank-pin. In it d' = diameter of the eccentric, and s = the throw of the eccentric. Bearing this in mind, formula A applies to an eccentric, as well as a crank; and if (as is often the case) $d + d'$ is greater than $10 s$, the formula would give $\sin. x$ greater than 1; but this is impossible, which shows that the friction is so great that there is no point of the revolution where the rotatory power is equal to it. Hence, an eccentric is never used for converting a rectilinear motion into a rotatory one; though the reverse is often done, where convenience of construction is of more importance than the loss of some power in friction. When an eccentric is used to produce a reciprocating rectilinear motion from a rotatory one, it is easily deduced, from what we have already said, that the loss of power from the friction of the eccentric and strap alone, independently of the bearings of the shaft, is equal to $\frac{1}{10}$ the power required to do the work, multiplied by the circumference of the eccentric, and divided by twice its throw. Or, in algebraic language, if

p = power to be transmitted by the eccentric,

the loss by the friction of the eccentric and strap

$$= \frac{p \times 3{\cdot}1416\, d'}{10 \times 2 \times s} = \frac{3{\cdot}1416\, p . d'}{20 s},$$

$$= {\cdot}15703 \frac{p\, d'}{s}$$

$$= p \times 0{\cdot}15703 \frac{d'}{s}.$$

From this it readily appears that, when $d' = \frac{s}{{\cdot}15703} = 6{\cdot}37\, s$; the power required to overcome the friction is equal to p.

Expressing this conclusion in words, we arrive at this result, that, (assuming the friction to be $\frac{1}{10}$ of the pressure,) when the diameter of an eccentric is 6·37 times the length of its throw, the power consumed in friction is equal to the power expended in doing the work required.

DIMENSIONS OF PARTS OF ENGINES.

We reserve for a subsequent part of the present Treatise the remarks we have to offer upon the Fly-wheel, Governor, and other moving parts of the engine, the theory of which requires to be considered; and these topics will be found to be fully elucidated at the several pages mentioned in the Index. We next proceed, though not strictly in order, to lay before our readers tables of dimensions of engines, computed from the formulæ given at page 106., and practical rules, which are an interpretation of those formulæ, and of some other formulæ given at page 157. The formulæ at page 106. have been constructed with much care: the results have been compared with the dimensions followed by the makers of most repute, and the tables and rules derived from them may be used by the engineer with confidence. For land engines various rules are scattered among the practical details, extending from page 206. to page 216., and which may be employed with safety in all cases where but a moderate pressure of steam is employed, such as was used in Mr. Watt's engines. The whole of the cranks, shafts, and other moving parts, of which the dimensions are given in the marine engine tables, are of malleable iron, with the exception of the side-lever, which is of cast iron. Many of the dimensions given in these tables must, we forsee, soon become obsolete, for the side-lever plan of engine, to which most of the sizes relate, is falling into disuse, and in marine engines the introduction of the screw propeller will also make great innovation. But many of the dimensions are applicable to any species of engine, and we have at page 224. given the dimensions of oscillating engines, followed by the most eminent constructors, and which are likely to remain unaffected by impending transformations. It may be useful, however, in addition, to give here the dimensions of one of Mr. Penn's 12 horse power oscillating engines for river steamers.

The cylinders of this oscillating engine are placed beneath the cranks, and, as in all Messrs. Penn's smaller engines, the piston rod is connected to the crank-pin by means of a brass cap, provided with a socket, by means of which it is cuttered to the piston rod. There is but one air-pump, which is situated within the condenser between the cylinders, and is worked by means of a crank in the intermediate shaft—this crank being cut out of a solid piece of metal, as in the formation of the cranked axles of locomotive engines. The steam enters the cylinder through the outer trunnions, or the trunnions adjacent to the ship's sides, and enters the condenser through the two midship trunnions—a short three-ported valve being placed on the front of the cylinder to regulate the flow of steam to and from the cylinder in the proper manner. This valve is balanced by a weight upon the other side of the cylinder, but in the most recent engines this weight is discarded, and two valves are used, which balance one another.

The framing consists of an upper and lower frame of cast iron, bound together by eight malleable iron columns: upon the lower frame the pillow-blocks rest which carry the cylinder trunnions, and the condenser and the bottom frame are cast in the same piece. The upper frame supports the paddle shaft pillow-blocks; and pieces are bolted on in continuation of the upper frame to carry the paddle wheels, which are overhung from the journal. The web, or base plate, of the lower frame is ¾ of an inch thick, and a cooming is carried all round the cylinder, leaving an opening of sufficient size to permit the necessary oscillation. The cross section of the upper frame is that of a hollow beam 6 in. deep, and about 3½ in. wide, with holes at the sides to take out the core; and the thickness of the metal is $\frac{11}{16}$ths of an inch. Both the upper and the lower frame is cast in a single piece, with the exception of the continuations of the upper frame, which support the paddle wheels. An oval ring 3 in. wide is formed in the upper frame, of sufficient size to permit the working of the air-pump crank; and from this ring, feathers run to the ends of the cross portions of the frame which support the intermediate shaft journals. The columns are 1¼ in. in diameter; they are provided with collars at the lower ends, which rest upon bosses in the lower frame, and with collars at the upper ends for supporting the upper frame; but the upper collars of two of the corner columns are screwed on, so as to enable the columns to be drawn up when it is required to get the cylinders out. The cross section of the bottom frame is also of the form of a hollow beam, 7 in. deep, except in the region of the condenser, where it is, of course, of a different form; the depth of the boss for the reception of the columns is a little more than 7 in. deep on the lower frame, and a little more than 6 in. deep on the upper frame; and the holes through them are so cored out, that the columns only bear at the upper and lower edges of the hole, instead of all through it—a formation by which the fitting of the columns is facilitated.

The condenser, which is cast upon the lower frame, consists of an oval vessel 22¼ in. wide, by 2 ft. 4¼ in. long, and 1 ft. 10¼ in. deep; it stands 9 in. above the upper face of the bottom frame, the rest projecting beneath it; and it is enlarged at the sides by being carried beneath the trunnions. The air pump, which is set in the centre of the condenser, is 15¼ in. in diameter, and has a stroke of 11 in. The foot valve is situated in the bottom of the air pump, and consists of a disc of brass, in which there is a rectangular flap valve, but rounded on one side to the circle of the pump, opening upwards, and so balanced as to enable the valve to open with facility; and the balance weight, which is formed of brass cast in the same piece as the valve itself, operates as a stop, by coming into contact with the disc which constitutes the bottom of the pump when the valve has opened sufficiently. This disc is bolted to the mouth of the pump by means of an internal flange, and before it can be removed by the pump, must be lifted out of its place. The air pump barrel is of brass, to which is bolted a cast-iron mouth piece, with a port for carrying the water to the hot well; and within the hot well the delivery valve, which consists of a common flap valve, is situated. The mouth piece and the air pump barrel are made tight to the condenser, and to one another, by means of metallic joints carefully scraped to a true surface, so that a little white or red lead interposed, makes an air-tight joint. The air pump bucket is of brass, and the valve of the bucket is of the common pot-lid, or spindle kind. The injection water enters through a single cock in front of the condenser, the jet striking against the barrel of the air pump: the air pump rod is maintained in its vertical position by means of guides, the lower ends of which are bolted to the mouth of the pump, and the upper to the oval in the top frame, within which the air pump crank works, and the motion is communicated from this crank to the pump rod by means of a short connecting rod. The lower frame is not set immediately below the top frame, but 2¼ in. behind it, and the air pump and condenser are 2¼ in. nearer one edge of the lower frame than the other.

The thickness of the metal of the cylinder is $\frac{9}{16}$ths of an inch; the depth of the belt of the cylinder is 9¼ in., and its greatest projection from the cylinder is 2¼ in. The distance from the lower edge of the belt to the bottom of the cylinder is 11¼ in., and from the upper edge of the belt to the top flange of the cylinder is 9 in. The trunnions are 7¼ in. diameter in the bearings, and 3¼ in. in width; and the flanges to which the glands are attached for screwing in the trunnion packings are 1¼ in. thick, and have

$\frac{7}{8}$ths of an inch of projection. The width of the packing space round the trunnions is $\frac{5}{8}$ths of an inch, and the diameter of the pipe passing through the trunnions 4$\frac{5}{8}$ths, which leaves $\frac{11}{16}$ths for the thickness of the metal of the bearing. The pipe leading to the condenser, from the cylinder, is made somewhat bell-mouthed where it joins the condenser, and the gland for compressing the packing is made of a larger internal diameter in every part except at the point the pipe emerges from it, where it accurately fits the pipe, so as to enable the gland to squeeze the packing. By this construction the gland may be drawn back without being jammed upon the enlarged part of the pipe, and the enlargement of the pipe towards the condenser prevents the air pump barrel from offering any impediment to the free egress of the steam. The gland is made altogether in four pieces: the ring which presses the packing is made distinct from the flange to which the bolts are attached which force the gland against the packing; and both ring and flange are made in two pieces, to enable them to be got over the pipe. The ring is half-checked in the direction of its depth, and is introduced without any other support to keep the halves together than what is afforded by the interior of the stuffing box; and the flange is half-checked in the direction of its thickness, so that the bolts which press down the ring by passing through this half-checked part also keep the segments of the flange together. The bottom of the trunnion packing space is contracted to the diameter of the eduction pipe, so as to prevent the packing from being squeezed into the jacket; but the eduction pipe does not fit quite tight into this contracted part, but, while in close contact on the lower side, has about $\frac{1}{32}$d of an inch of space between the top of the pipe and the cylinder, so as to permit the trunnions to wear to that extent without throwing a strain upon the pipe. The eduction pipe is attached to the condenser by a flange joint, and the bolt-holes are all made somewhat oblong in the perpendicular direction, so as to permit the pipe to be slightly lowered, should such an operation be rendered necessary by the wear of the trunnion bearings; but in practice the wear of the trunnion bearings is found to be so small, as to be almost inappreciable. It is not expedient to cast the trunnion plummer-blocks upon the lower frame, as is sometimes done; for the cylinders, being pressed from the steam trunnions by the steam, and drawn in the direction of the condenser by the vacuum, have a continual tendency to approach one another; and as they wear slightly towards midships there would be no power of re-adjustment unless the plummer-blocks were moveable. The flanges of the trunnions should always fit tight against the plummer-block sides, but there should be a little play sideways at the necks of the trunnions, so that the cylinder may be enabled to expand when heated, without throwing an undue strain upon the trunnion supports. Above and below each trunnion, a feather, or bracket, runs from the edge of the belt, between 3 in. and 4 in. along the cylinder, for the sake of additional support; and in large engines this feather is continued through the interior of the belt, and cruciform feathers are added for the sake of greater stiffness. The projection of the outer face of the trunnion flange from the side of the cylinder is 6$\frac{1}{4}$ in.; the thickness of the flange round the mouth of the cylinder is $\frac{3}{4}$ of an inch, and its projection 1$\frac{7}{8}$ in.; the height of the cylinder stuffing box above the cylinder cover is 4$\frac{1}{8}$ in., and its external diameter 4$\frac{3}{8}$ in.—the diameter of the piston rod being 2$\frac{1}{8}$ in.; and the thickness of the stuffing box flange is 1$\frac{1}{8}$ in. The length of the valve casing is 16$\frac{1}{2}$ in., and its projection from the cylinder is 3$\frac{1}{4}$ in. at the top, 4$\frac{1}{4}$ in. at the centre, and 2$\frac{1}{2}$ in. at the bottom, so that the back of the valve casing is not made flat, but is formed in a curve. The width of the valve casing is 9 in., but there is a portion of the depth of the belt 1$\frac{1}{4}$ in. wider, to permit the steam to enter from the belt into the casing. The valve casing is attached to the cylinder by a metallic joint; the width of the flange of this joint is 1$\frac{3}{4}$ in., the thickness of the flange on the casing $\frac{1}{2}$ in., and the thickness of the flange on the cylinder $\frac{5}{8}$ths of an inch. The valve is of the ordinary three-ported description, and both cylinder and valve faces are of cast iron. The projection from the cylinder of the passage for carrying the steam upwards and downwards, from the valve to the top and bottom of the cylinder, is 2$\frac{1}{4}$ in., and its width externally 8$\frac{5}{8}$ in.

The piston is packed with hemp, but the junk ring is made of malleable iron, as cast-iron junk rings have been found liable to break: there are four plugs screwed into the cylinder cover, which, when removed, permit a box-key to be introduced, to screw down the piston packings. The screws in the junk ring are each provided with a small ratchet, cut in a fixed washer upon the head, to prevent the screw from turning back; and the number of clicks given by these ratchets, in tightening up the bolts, enables the engineer to know when they have all been tightened equally. The cap for attaching the piston rod to the crank-pin is formed altogether of brass, which brass serves to form the bearing of the crank-pin. The external diameter of the socket by which this cap is attached to the piston rod is 3$\frac{5}{16}$ in. The diameter of the crank-pin is 3 in., and the length of the crank-pin bearing 3$\frac{7}{8}$ in. The thickness of the brass around the crank-pin bearing is 1 in., and the upper portion of the brass is secured to the lower portion by means of lugs, which are of such a depth that the perpendicular section through the centre of the bearing has a square outline measuring 7 in. in the horizontal direction, 3$\frac{7}{8}$ in. from the centre of the pin to the level of the top of the lugs, and 2$\frac{1}{8}$ in. from the centre of the pin to the level of the bottom of the lugs. The width of the lugs is 2 in., and the bolts passing through them are 1$\frac{1}{4}$ in. in diameter. The bolts are tapped into the lower portion of the cap, and are fitted very accurately by scraping where they pass through the upper portion, so as to act as steady pins in preventing the cover of the crank-pin bearing from being worked sideways by the alternate thrust on each side. The distance between the centres of the bolts is 5 in., and in the centre of the cover, where the lugs, continued in the form of a web, meet one another, an oil cup 1$\frac{5}{8}$ in. in diameter, 1$\frac{1}{8}$ in. high, and provided with an internal pipe, is cast upon the cover, to contain oil for the lubrication of the crank-pin bearing. The depth of the cutter for attaching the cap to the piston rod is 1$\frac{1}{4}$ in., and its thickness is $\frac{5}{8}$ in. A similar cap attaches the air pump crank to the connecting rod by which the air pump rod is moved, but in this instance the diameter of the bearing is 5 in., and the length of the bearing about 3 in. The thickness of the brass encircling the bearing is $\frac{3}{4}$ in. upon the edge, and 1$\frac{1}{8}$ in. in the centre, the back being slightly rounded; the width of the lugs is 1$\frac{5}{8}$ in., and the depth of the lugs is 2 in. upon the upper brass, and 2 in. upon the lower brass, making a total depth of 4 in. The diameter of the bolts passing through the lugs is 1 in., and the bolts are tapped into the lower brass, and accurately fitted into the upper one, so as to act as steady pins, as in the previous instance. The lower eye of the connecting rod is forked so as to admit the eye of the air pump rod; and the pin which connects the two together is prolonged into a cross head, the ends of which move in the guides. The forked end of the connecting rod is fixed upon the cross head by means of a feather, so that the cross head partakes of the motion of the connecting rod, and a cap, similar to that attached to the piston rod, is attached to the air pump rod, for connecting it with the cross head. The diameter of the air pump rod is 1$\frac{3}{8}$ in., the external diameter of the socket encircling the rod is 2$\frac{5}{8}$ in., and the depth of the socket 4$\frac{1}{4}$ in. from the centre of the cross head. The depth of the cutter for attaching the socket to the rod is 1 in., and its thickness $\frac{5}{16}$ in. The breadth of the lugs is 1$\frac{5}{8}$ in., the depth 1$\frac{1}{4}$ in., making a total depth of 2$\frac{3}{4}$ in.: and the diameter of the bolts $\frac{7}{8}$ of an inch. The diameter of the cross head at the centre is 2 in., the thickness of each jaw around the bearing 1 in., and the breadth of each $\frac{9}{16}$ in.

The diameter of the intermediate shaft journal is 4$\frac{3}{16}$ in., and of the paddle shaft journal 4$\frac{5}{8}$ in.; the length of the journal in each case is 5 in. The diameter of the large eye of the crank is 7 in., and the diameter of the hole through it is 4$\frac{5}{8}$ in.; the diameter of the small eye of the crank is 5$\frac{1}{4}$ in., the diameter of the hole through it being 3 in. The depth of the large eye is 4$\frac{1}{2}$ in., and of the small eye 3$\frac{3}{4}$ in.; the breadth of the web is 4 in. at the shaft end, and 3 in. at the pin end, and the thickness of the web is 2$\frac{5}{8}$ in. The width of the notch forming the crank in the intermediate shaft for working the air pump is 3$\frac{1}{2}$ in., and the width of each of the arms of this crank is 3$\frac{11}{16}$ in.; both the outer and inner corners of the crank are chamfered away, until the square part of the crank meets the round of the shaft. The method of securing the crank-pins into the crank eyes of the intermediate shaft, consists in the application of a nut to the end of each pin, where it passes through the eye, the projecting end of the pin being formed with a thread, upon which the nut is screwed.

The eccentric strap is half an inch thick, and 1$\frac{1}{4}$ in. broad; and the flanges of the eccentric, within which the strap works, are each $\frac{5}{8}$ of an inch thick. The eccentric is put on in two halves, joined in the diameter of largest eccentricity by means of a single bolt passing through lugs on the central eye, and the back balance is made in a separate piece $\frac{5}{8}$ of an inch thick, and is attached by means of two bolts, which also help to bind the halves of the eccentric together. The eccentric rod is attached to the eccentric hoops by means of two bolts passing through lugs upon the rod, and tapped into a square boss upon the hoop; and pieces of iron, of a greater or less thickness, are interposed between the surfaces in setting the valve, to make the eccentric rod of the right length. The eccentric rod is kept in gear by the pull of a small horizontal rod, attached to a vertical blade spring, and it is thrown out of gear by means of the ordinary disengaging apparatus, which acts in opposition to the spring, as, in cases where the eccentric rod is not vertical, it acts in opposition to the gravity of the rod. The paddle shaft plummer-blocks are altogether of brass, and are formed in much the same manner as the cap of the piston rod, only that the sole is flat, as in ordinary plummer-blocks, and is fitted between projecting lugs of the framing, to prevent side motion. In the bearings fitted on this plan, however, the upper brass will generally acquire a good deal of play after some amount of wear. The bolts are worked slack in the holes, though accurately fitted at first; and it appears expedient, therefore, either to make the bolts very large, and the sockets through which they pass very deep, or to let one brass fit into the other. The trunnion plummer-blocks are formed in the same manner as the shaft plummer-blocks; the nuts are kept from turning back by means of a pinching screw passing through a stationary washer.

Length of Stroke in Feet.

Diameter of Cylinder in Inches.	Breadth of Web of Crank at Paddle Shaft Centre.															Diameter of Cylinder in Inches.
	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	
20	5·28	5·45	5·62	6·04	6·46	6·72	6·98	7·19	7·40	7·59	7·78	7·95	8·12	8·29	8·44	20
21	5·51	5·68	5·85	6·27	6·68	6·94	7·21	7·42	7·63	7·83	8·04	8·20	8·39	8·56	8·71	21
22	5·74	5·91	6·08	6·49	6·90	7·16	7·44	7·65	7·86	8·07	8·30	8·45	8·65	8·83	8·98	22
23	5·96	6·14	6·31	6·72	7·12	7·38	7·67	7·88	8·09	8·31	8·55	8·70	8·90	9·09	9·25	23
24	6·18	6·36	6·54	6·94	7·33	7·60	7·89	8·11	8·32	8·55	8·80	8·95	9·16	9·35	9·52	24
25	6·40	6·58	6·77	7·16	7·54	7·82	8·11	8·34	8·55	8·79	9·04	9·20	9·41	9·61	9·79	25
26	6·62	6·80	7·00	7·38	7·75	8·04	8·33	8·57	8·78	9·03	9·28	9·45	9·67	9·87	10·06	26
27	6·84	7·03	7·23	7·60	7·96	8·26	8·55	8·80	9·01	9·27	9·51	9·70	9·92	10·13	10·33	27
28	7·06	7·25	7·46	7·82	8·17	8·48	8·77	9·03	9·24	9·51	9·74	9·95	10·18	10·39	10·59	28
29	7·28	7·48	7·69	8·04	8·38	8·70	8·99	9·26	9·47	9·75	9·97	10·20	10·43	10·65	10·85	29
30	7·50	7·71	7·92	8·26	8·60	8·92	9·24	9·49	9·74	9·98	10·22	10·45	10·68	10·89	11·10	30
31	7·65	7·88	8·11	8·46	8·80	9·13	9·44	9·72	9·96	10·20	10·44	10·69	10·92	11·13	11·34	31
32	7·80	8·05	8·30	8·66	9·00	9·34	9·64	9·94	10·28	10·42	10·67	10·93	11·16	11·37	11·58	32
33	7·95	8·22	8·49	8·85	9·20	9·54	9·84	10·15	10·50	10·64	10·89	11·16	11·39	11·61	11·82	33
34	8·10	8·39	8·68	9·04	9·40	9·74	10·04	10·35	10·71	10·86	11·12	11·39	11·62	11·85	12·06	34
35	8·25	8·56	8·87	9·23	9·59	9·94	10·24	10·55	10·92	11·08	11·34	11·62	11·85	12·08	12·29	35
36	8·40	8·73	9·06	9·42	9·79	10·14	10·44	10·75	11·13	11·30	11·56	11·85	12·08	12·31	12·53	36
37	8·55	8·90	9·25	9·61	9·99	10·34	10·64	10·95	11·34	11·52	11·78	12·07	12·31	12·54	12·76	37
38	8·70	9·07	9·44	9·80	10·18	10.54	10·84	11·15	11·55	11·74	12·00	12·29	12·54	12·77	12·99	38
39	8·85	9·24	9·62	9·89	10·37	10·73	11·04	11·35	11·76	11·96	12·23	12·51	12·77	13·00	13·23	39
40	9·00	9·40	9·80	10·18	10·56	10·90	11·24	11·56	11·88	12·17	12·46	12·72	12·98	13·23	13·43	40
41	9·19	9·59	9·99	10·37	10·75	11·08	11·41	11·73	12·05	12·37	12·67	12·95	13·22	13·46	13·71	41
42	9·38	9·78	10·17	10·56	10·94	11·25	11·57	11·89	12·22	12·57	12·87	13·18	13·46	13·69	13·94	42
43	9·57	9·97	10·36	10·75	11·13	11·42	11·72	12·05	12·39	12·76	13·08	13·40	13·70	13·92	14·16	43
44	9·76	10·15	10·55	10·94	11·32	11·59	11·87	12·21	12·56	12·95	13·28	13·62	13·93	14·15	14·38	44
45	9·94	10·33	10·74	11·13	11·51	11·76	12·02	12·37	12·73	13·14	13·49	13·83	14·17	14·38	14·60	45
46	10·12	10·51	10·93	11·32	11·70	11·93	12·17	12·53	12·90	13·32	13·69	14·05	14·40	14·61	14·82	46
47	10·30	10·69	11·11	11·51	11·89	12·10	12·32	12·69	13·07	13·50	13·90	14·27	14·63	14·84	15·04	47
48	10·48	10·87	11·30	11·70	12·08	12·27	12·47	12·85	13·24	13·68	14·10	14·49	14·87	15·07	15·26	48
49	10·67	11·06	11·49	11·89	12·27	12·44	12·62	13·01	13·41	13·85	14·31	14·71	15·10	15·30	15·48	49
50	10·86	11·27	11·68	12·07	12·46	12·61	12·76	13·17	13·58	14·06	14·54	14·94	15·34	15·52	15·70	50
51	11·03	11·45	11·87	12·26	12·65	12·82	12·99	13·40	13·81	14·27	14·74	15·14	15·53	15·72	15·92	51
52	11·20	11·63	12·06	12·44	12·84	13·03	13·22	13·63	14·04	14·48	14·94	15·34	15·71	15·92	16·14	52
53	11·37	11·81	12·24	12·63	13·03	13·24	13·45	13·86	14·26	14·69	15·14	15·53	15·90	16·12	16·35	53
54	11·54	11·98	12·42	12·81	13·22	13·45	13·68	14·09	14·49	14·90	15·34	15·72	16·08	16·32	16·56	54
55	11·71	12·15	12·60	13·00	13·41	13·66	13·91	14·32	14·72	15·12	15·54	15·91	16·27	16·51	16·77	55
56	11·88	12·32	12·78	13·18	13·60	13·87	14·15	14·55	14·95	15·33	15·74	16·10	16·45	16·71	16·98	56
57	12·04	12·49	12·97	13·37	13·79	14·08	14·38	14·78	15·18	15·54	15·94	16·29	16·64	16·91	17·20	57
58	12·20	12·66	13·15	13·56	13·98	14·29	14·62	15·01	15·41	15·75	16·14	16·48	16·82	17·11	17·41	58
59	12·36	12·84	13·33	13·75	14·17	14·50	14·86	15·24	15·64	15·96	16·34	16·67	17·01	17·30	17·60	59
60	12·52	13·01	13·51	13·94	14·37	14·73	15·10	15·47	15·84	16·19	16·54	16·86	17·19	17·50	17·82	60
61	12·74	13·21	13·70	14·13	14·55	14·91	15·29	15·66	16·03	16·39	16·73	17·06	17·39	17·70	18·03	61
62	12·96	13·41	13·89	14·32	14·73	15·10	15·48	15·85	16·22	16·58	16·92	17·25	17·59	17·90	18·23	62
63	13·17	13·61	14·08	14·51	14·91	15·38	15·67	16·04	16·41	16·77	17·12	17·45	17·79	18·10	18·43	63
64	13·38	13·81	14·26	14·69	15·09	15·57	15·86	16·23	16·60	17·97	17·31	17·65	17·99	18·30	18·64	64
65	13·59	14·01	14·45	14·87	15·27	15·75	16·05	16·42	16·79	18·17	17·51	17·84	18·18	18·51	18·84	65
66	13·80	14·21	14·63	15·05	15·45	15·94	16·23	16·61	16·98	18·36	17·70	18·04	18·38	18·71	19·05	66
67	14·01	14·41	14·82	15·23	15·63	16·12	16·41	16·80	17·17	18·55	17·90	18·23	18·58	18·91	19·25	67
68	14·22	14·61	15·00	15·41	15·81	16·31	16·60	16·98	17·36	18·74	18·09	18·43	18·78	19·11	19·45	68
69	14·43	14·81	15·19	15·59	15·99	16·49	16·78	17·16	17·55	18·93	18·29	18·63	18·98	19·31	19·65	69
70	14·64	15·01	15·38	15·77	16·17	16·57	16·97	17·35	17·74	18·11	18·48	18·83	19·18	19·51	19·85	70
71	14·83	15·20	15·57	15·89	16·37	16·75	17·14	17·53	17·93	18·30	18·67	19·03	19·38	19·71	20·06	71
72	15·02	15·39	15·75	16·08	16·56	16·93	17·30	17·71	18·12	18·49	18·86	19·22	19·58	19·91	20·26	72
73	15·21	15·58	15·94	16·27	16·76	17·11	17·47	17·88	18·31	18·68	19·05	19·41	19·77	20·10	20·46	73
74	15·40	15·77	16·12	16·46	16·95	17·29	17·63	18·06	18·49	18·87	19·24	19·60	19·97	20·30	20·67	74
75	15·59	15·96	16·31	16·65	17·15	17·47	17·80	18·23	18·67	19·06	19·43	19·79	20·16	20·50	20·87	75
76	15·78	16·15	16·49	16·84	17·34	17·65	17·97	18·41	18·86	19·24	19·62	19·98	20·35	20·70	21·07	76
77	15·97	16·34	16·68	17·03	17·54	17·83	18·13	18·58	19·04	19·43	19·81	20·17	20·54	20·89	21·27	77
78	16·16	16·53	16·87	17·22	17·73	18·01	18·30	18·76	19·23	19·61	20·00	20·36	20·73	21·09	21·48	78
79	16·35	16·71	17·05	17·41	17·92	18·19	18·46	18·93	19·41	19·80	20·19	20·55	20·92	21·29	21·68	79
80	16·54	16·89	17·24	17·68	18·12	18·37	18·61	19·11	19·61	19·99	20·38	20·74	21·11	21·49	21·88	80
81	16·74	17·08	17·42	17·86	18·30	18·56	18·82	19·31	19·80	20·18	20·57	20·93	21·31	21·69	22·08	81
82	16·94	17·27	17·60	18·04	18·47	18·75	19·03	19·51	19·99	20·37	20·76	21·12	21·51	21·89	22·27	82
83	17·13	17·46	17·79	18·22	18·65	18·94	19·24	19·70	20·18	20·56	20·95	21·31	21·70	22·08	22·46	83
84	17·32	17·65	17·98	18·40	18·82	19·13	19·45	19·90	20·36	20·74	21·14	21·56	21·89	22·27	22·65	84
85	17·52	17·84	18·17	18·58	19·00	19·32	19·65	20·09	20·55	20·93	21·33	21·69	22·09	22·46	22·84	85
86	17·71	18·03	18·36	18·76	19·17	19·51	19·85	20·29	20·73	21·11	21·52	21·88	22·28	22·65	23·03	86
87	17·90	18·22	18·55	18·94	19·35	19·70	20·06	20·48	20·92	21·30	21·70	22·07	22·47	22·84	23·22	87
88	18·09	18·41	18·73	19·12	19·52	19·89	20·26	20·68	21·10	21·48	21·89	22·26	22·67	23·03	23·41	88
89	18·28	18·60	18·92	19·20	19·70	20·08	20·46	20·87	21·29	21·67	22·07	22·45	22·86	23·22	23·60	89
90	18·47	18·79	19·11	19·49	19·87	20·27	20·67	21·07	21·47	21·86	22·26	22·64	23·03	23·41	23·79	90
91	18·67	18·99	19·30	19·68	20·06	20·46	20·86	21·26	21·66	22·05	22·45	22·83	23·22	23·60	23·98	91
92	18·87	19·18	19·49	19·87	20·25	20·64	21·04	21·44	21·84	22·24	22·64	23·02	23·41	23·79	24·17	92
93	19·06	19·37	19·68	20·06	20·43	20·83	21·23	21·63	22·03	22·42	22·82	23·21	23·60	23·98	24·36	93
94	19·26	19·56	19·87	20·25	20·62	21·01	21·41	21·81	22·21	22·61	23·01	23·39	23·79	24·17	24·55	94
95	19·45	19·75	20·06	20·44	20·80	21·20	21·60	22·00	22·40	22·89	23·19	23·58	23·97	24·86	24·74	95
96	19·64	19·94	20·25	20·63	20·99	21·38	21·78	22·18	22·48	23·08	23·38	23·76	24·16	24·55	24·93	96
97	19·83	20·13	20·44	20·82	21·17	21·57	21·97	22·37	22·67	23·26	23·56	23·95	24·34	24·74	25·12	97
98	20·02	20·32	20·63	21·00	21·36	21·75	22·15	22·55	22·85	23·45	23·75	24·13	24·53	24·93	25·31	98
99	20·21	20·51	20·82	21·18	21·54	21·94	22·34	22·74	23·04	23·63	23·93	24·32	24·71	25·11	25·50	99
100	20·40	20·70	21·00	21·36	21·73	22·12	22·52	22·92	23·32	23·72	24·12	24·51	24·90	25·29	25·68	100

DIMENSIONS OF SEVERAL

Diameters in Inches.	Thickness of Large Eye of Crank.														
Length of Stroke in Feet.	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9
20	1·71	1·80	1·89	1·97	2·05	2·12	2·19	2·25	2·32	2·38	2·44	2·50	2·55	2·60	2·64
21	1·77	1·87	1·95	2·04	2·13	2·20	2·27	2·32	2·40	2·46	2·52	2·58	2·64	2·70	2 75
22	1·83	1·93	2·01	2·11	2·20	2·28	2·35	2·39	2·48	2·54	2·60	2·66	2·72	2·80	2·86
23	1·89	1·99	2·07	2·18	2·28	2·36	2·43	2·46	2·56	2·62	2·68	2·74	2·80	2·89	2·97
24	1·95	2·06	2·14	2·25	2·35	2·44	2·51	2·54	2·64	2·70	2·76	2·82	2·88	2·98	3·08
25	2·01	2·12	2·21	2·32	2·43	2·52	2·59	2·62	2·72	2·78	2·84	2·90	2·96	3·07	3·18
26	2·07	2·19	2·28	2·39	2·50	2·59	2·66	2·70	2·80	2·85	2·92	2·98	3·04	3·16	3·28
27	2·13	2·25	2·35	2·46	2·58	2·66	2·73	2·78	2·87	2·92	2·99	3·06	3·12	3·25	3·38
28	2·19	2·31	2·42	2·53	2·65	2·73	2·80	2·86	2·94	2·99	3·06	3·13	3·20	3·34	3·48
29	2·25	2·37	2·49	2·60	2·73	2·80	2·87	2·94	3·01	3·06	3·13	3·20	3·28	3·43	3·58
30	2·30	2·43	2·56	2·68	2·80	2·87	2·94	3·01	3·08	3·13	3·18	3·27	3·36	3·52	3·68
31	2·36	2·50	2·63	2·74	2·87	2·94	3·00	3·07	3·15	3·21	3·26	3·34	3·43	3·58	3·73
32	2·42	2·56	2·69	2·80	2·94	3·01	3·06	3·13	3·22	3·28	3·34	3·41	3·50	3·64	3·78
33	2·49	2·62	2·75	2·86	3·00	3·08	3·12	3·20	3·29	3·35	3·41	3·48	3·57	3·70	3·83
34	2·55	2·69	2·81	2·92	3·06	3·15	3·18	3·27	3·36	3·42	3·48	3·55	3·64	3·76	3·88
35	2·61	2·75	2·87	2·98	3·12	3·22	3·25	3·34	3·43	3·49	3·55	3·62	3·71	3·82	3·93
36	2·67	2·81	2·93	3·04	3·18	3·29	3·32	3·41	3·50	3·56	3·62	3·69	3·78	3·88	3·98
37	2·74	2·87	2·99	3·10	3·24	3·35	3·39	3·48	3·57	3·63	3·69	3·76	3·85	3·94	4·03
38	2·81	2·94	3·05	3·16	3·30	3·41	3·46	3·55	3·64	3·70	3·77	3·83	3·91	4·00	4·07
39	2·87	3·00	3·11	3·22	3·36	3·47	3·53	3·62	3·71	3·77	3·84	3·90	3·97	4·04	4·11
40	2·93	3·05	3·17	3·29	3·42	3·51	3·60	3·69	3·78	3·84	3·90	3·96	4·03	4·09	4·15
41	3·03	3·13	3·24	3·37	3·49	3·58	3·67	3·75	3·85	3·92	3·98	4·04	4·11	4·17	4·24
42	3·13	3·22	3·31	3·45	3·56	3·65	3·74	3·81	3·92	3·99	4·06	4·12	4·19	4·25	4·32
43	3·23	3·30	3·39	3·53	3·63	3·72	3·81	3·87	3·99	4·06	4·14	4·20	4·27	4·33	4·40
44	3·33	3·39	3·47	3·60	3·69	3·79	3·88	3·94	4·06	4·13	4·22	4·28	4·35	4·41	4·48
45	3·43	3·47	3·55	3·67	3·75	3·86	3·95	4·01	4·13	4·19	4·30	4·36	4·43	4·49	4·56
46	3·53	3·56	3·63	3·74	3·81	3·93	4·02	4·08	4·19	4·26	4·38	4·44	4·51	4·57	4·64
47	3·63	3·64	3·71	3·81	3·87	4·00	4·09	4·15	4·25	4·32	4·45	4·52	4·59	4·65	4·72
48	3·73	3·73	3·79	3·88	3·93	4·06	4·15	4·22	4·32	4·38	4·52	4·59	4·66	4·73	4·80
49	3·83	3·82	3·87	3·95	3·99	4·12	4·21	4·29	4·39	4·44	4·59	4·66	4.73	4·81	4·88
50	3·93	3·92	3·95	4·02	4·09	4·18	4·27	4·36	4·46	4·55	4·64	4·72	4·81	4·88	4·96
51	4·02	3·99	4·02	4·10	4·17	4·24	4·34	4·42	4·53	4·62	4·71	4·79	4·88	4·95	5·03
52	4·10	4·05	4·09	4·18	4·24	4·31	4·41	4·48	4·60	4·69	4·78	4·86	4·95	5·02	5·10
53	4·19	4·12	4·16	4·26	4·31	4·38	4·48	4·54	4·67	4·76	4·85	4·93	5·02	5·09	5·17
54	4·28	4·19	4·24	4·33	4·38	4·45	4·55	4·61	4·74	4·82	4·92	5·00	5·09	4·16	5·24
55	4·36	4·26	4·32	4·40	4·45	4·52	4·62	4·68	4·81	4·88	4·99	5·07	5·16	5·23	5·31
56	4·45	4·33	4·40	4·47	4·52	4·59	4·69	4·75	4·88	4·94	5·06	5·14	5·23	5·30	5·38
57	4·53	4·40	4·48	4·54	4·59	4·66	4·76	4·82	4·94	5·01	5·13	5·20	5·30	5·37	5·45
58	4·62	4·46	4·56	4·61	4·66	4·73	4·83	4·89	5·00	5·08	5·19	5·26	5·37	5·44	5·52
59	4·70	4·53	4·64	4·68	4·73	4·80	4·89	4·96	5·06	5·14	5·25	5·32	5·43	5·51	5·59
60	4·79	4·60	4·72	4·76	4·80	4·87	4·95	5·03	5·12	5·21	5·31	5·38	5·49	5·57	5·66
61	4·89	4·70	4·80	4·83	4·88	4·95	5·02	5·10	5·19	5·28	5·38	5·45	5·56	5·64	5·73
62	4·98	4·80	4·88	4·90	4·96	5·02	5·09	5·17	5·26	5·35	5·45	5·52	5·63	5·71	5·80
63	5·07	4·90	4·96	4·97	5·03	5·09	5·16	5·24	5·33	5·41	5·52	5·59	5·70	5·78	5·87
64	5·16	5·00	5·04	5·03	5·10	5·16	5·23	5·31	5·40	5·48	5·59	5·66	5·77	5·85	5·94
65	5·25	5·10	5·12	5·09	5·17	5·23	5·30	5·38	5·47	5·55	5·66	5·73	5·84	5·92	6·01
66	5·34	5·20	5·20	5·15	5·24	5·30	5·37	5·45	5·54	5·62	5·73	5·80	5·90	5·98	6·08
67	5·43	5·30	5·28	5·21	5·31	5·37	5·44	5·52	5·61	5·69	5·80	5·87	5·97	6·04	6·15
68	5·52	5·40	5·35	5·27	5·38	5·44	5·51	5·59	5·68	5·76	5·87	5·93	6·04	6·10	6·22
69	5·61	5·50	5·42	5·33	5·45	5·51	5·58	5·66	5·75	5·83	5·94	5·99	6·10	6·17	6·29
70	5·70	5·60	5·49	5·40	5·52	5·58	5·64	5·72	5·80	5·89	5·98	6·06	6·16	6·25	6·35
71	5·80	5·69	5·58	5·48	5·60	5·66	5·72	5·79	5·87	5·96	6·05	6·13	6·23	6·32	6·42
72	5·90	5·78	5·67	5·56	5·68	5·74	5·80	5·86	5·94	6·03	6·12	6·20	6·30	6·39	6·49
73	5·99	5·87	5·76	5·64	5·76	5·82	5·88	5·93	6·01	6·10	6·19	6·27	6·37	6·46	6·56
74	6·09	5·96	5·84	5·72	5·84	5·89	5·95	6·00	6·08	6·17	6·26	6·34	6·44	6·53	6·63
75	6·18	6·05	5·92	5·80	5·91	5·96	6·02	6·07	6·15	6·24	6·33	6·41	6·51	6·60	6·69
76	6·27	6·14	6·00	5·88	5·98	6·03	6·09	6·14	6·22	6·31	6·40	6·48	6·58	6·66	6·75
77	6·36	6·23	6·08	5·95	6·05	6·10	6·16	6·21	6·29	6·38	6·46	6·55	6·64	6·73	6·81
78	6·46	6·32	6·16	6·02	6·12	6·17	6·23	6·28	6·36	6·45	6·53	6·62	6·71	6·80	6·87
79	6·56	6·41	6·24	6·09	6·19	6·24	6·30	6·35	6·43	6·52	6·60	6·69	6·77	6·86	6·93
80	6·66	6·49	6·32	6·16	6·26	6·31	6·37	6·43	6·50	6·58	6·66	6·75	6·84	6·93	7·02
81	6·76	6·59	6·41	6·25	6·34	6·39	6·44	6·50	6·57	6·65	6·73	6·82	6·91	7·00	7·09
82	6·86	6·69	6·50	6·35	6·42	6·46	6·51	6·57	6·64	6·72	6·80	6·89	6·98	7·07	7·16
83	6·96	6·79	6·59	6·44	6·50	6·54	6·58	6·64	6·71	6·79	6·87	6·96	7·05	7·14	7·23
84	7·06	6·88	6·68	6·54	6·58	6·61	6·65	6·71	6·78	6·86	6·94	7·03	7·12	7·21	7·30
85	7·17	6·97	6·76	6·63	6·66	6·69	6·72	6·78	6·84	6·93	7·01	7·10	7·19	7·28	7·37
86	7·27	7·06	6·84	6·73	6·74	6·76	6·79	6·85	6·90	7·00	7·08	7·17	7·26	7·35	7·44
87	7·37	7·15	6·92	6·82	6·82	6·84	6·86	6·92	6·96	7·06	7·15	7·24	7·33	7·42	7·51
88	7·47	7·24	7·00	6·92	6·90	6·91	6·93	6·99	7·02	7·12	7·21	7·30	7·39	7·48	7·57
89	7·57	7·33	7·09	7·01	6·98	6·99	7·00	7·06	7·08	7·18	7·27	7·36	7·45	7·54	7·63
90	7·67	7·42	7·18	7·11	7·05	7·06	7·08	7·11	7·14	7·24	7·34	7·42	7·51	7·60	7·69
91	7·78	7·52	7·28	7·20	7·13	7·14	7·16	7·19	7·22	7·32	7·41	7·49	7·58	7·67	7·76
92	7·88	7·62	7·37	7·29	7·21	7·22	7·23	7·27	7·30	7·40	7·48	7·56	7·65	7·74	7·83
93	7·99	7·72	7·46	7·38	7·29	7·30	7·31	7·35	7·38	7·48	7·55	7·63	7·72	7·81	7·90
94	8·09	7·81	7·55	7·47	7·37	7·38	7·38	7·43	7·45	7·55	7·62	7·70	7·79	7·89	7·97
95	8·20	7·90	7·64	7·56	7·45	7·46	7·46	7·51	7·52	7·62	7·69	7·77	7·86	7·96	8·04
96	8·31	7·99	7·73	7·65	7·53	7·54	7·53	7·59	7·60	7·69	7·76	7·84	7·93	8·02	8·11
97	8·41	8·08	7·82	7·73	7·61	7·62	7·61	7·66	7·68	7·76	7·83	7·91	8·00	8·08	8·18
98	8·52	8·17	7·91	7·81	7·69	7·70	7·68	7·73	7·76	7·83	7·90	7·98	8·06	8·15	8·24
99	8·62	8·26	8·00	7·89	7·77	7·77	7·75	7·80	7·83	7·90	7·97	8·05	8·12	8·21	8·30
100	8·72	8·40	8·09	7·97	7·86	7·84	7·83	7·87	7·91	7·97	8·04	8·11	8·19	8·27	8·36

PARTS OF CRANK.

Thickness of Web of Crank at Paddle Shaft Centre.															Diameters in Inches.
2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	
2·64	2·72	2·81	3·02	3·23	3·36	3·49	3·59	3·70	3·79	3·89	3·97	4·06	4·14	4·22	20
2·75	2·84	2·93	3·14	3·34	3·47	3·61	3·71	3·82	3·91	4·02	4·10	4·19	4·27	4·36	21
2·86	2·96	3·05	3·25	3·45	3·58	3·73	3·83	3·94	4·03	4·14	4·23	4·32	4·40	4·50	22
2·97	3·08	3·17	3·36	3·56	3·69	3·85	3·95	4·06	4·15	4·26	4·36	4·45	4·53	4·64	23
3·08	3·19	3·29	3·47	3·67	3·80	3·97	4·07	4·18	4·27	4·38	4·49	4·58	4.66	4·77	24
3·19	3·30	3·41	3·58	3·78	3·91	4·09	4·19	4·30	4·39	4·50	4·62	4·71	4·79	4·90	25
3·30	3·41	3·52	3·69	3·89	4·02	4·20	4·30	4·42	4·51	4·62	4·74	4·84	4·92	5·03	26
3·41	3·52	3·63	3·80	4·00	4·13	4·31	4·41	4·53	4·63	4·74	4·86	4·97	5·05	5·16	27
3·52	3·63	3·74	3·91	4·10	4·24	4·42	4·52	4·64	4·75	4·86	4·98	5·10	5·18	5·29	28
3·63	3·74	3·85	4·02	4·20	4·35	4·53	4·63	4·75	4·87	4·98	5·10	5·22	5·31	5·42	29
3·75	3·85	3·96	4·13	4·30	4·46	4·62	4·74	4·87	4·99	5·11	5·22	5·34	5·44	5·55	30
3·83	3·94	4·06	4·23	4·39	4·56	4·72	4·85	4·98	5·10	5·23	6·34	5·46	5·56	5·67	31
3·91	4·03	4·16	4·33	4·49	4·66	4·82	4·96	5·09	5·21	5·34	5·46	5·57	5·68	5·79	32
3·99	4·12	4·26	4·43	4·59	4·76	4·92	5·07	5·20	5·32	5·45	5·58	5·69	5·80	5·91	33
4·07	4·21	4·36	4·53	4·69	4·86	5·02	5·18	5·31	5·43	5·57	5·70	5·80	5·92	6·03	34
4·15	4·30	4·45	4·62	4·79	4·96	5·12	5·28	5·42	5·54	5·68	5·81	5·92	6·03	6·15	35
4·22	4·38	4·54	4·71	4·89	5·06	5·22	5·38	5·53	5·65	5·79	5·92	6·03	6·15	6·27	36
4·29	4·46	4·63	4·80	4·98	5·16	5·32	5·48	5·64	5·76	5·90	6·03	6·15	6·26	6·39	37
4·36	4·54	4·72	4·89	5·08	5·26	5·42	5·58	5·74	5·87	6·01	6·14	6·26	6·37	6·51	38
4·43	4·62	4·81	4·98	5·18	5·36	5·52	5·68	5·84	5·98	6·12	6·25	6·38	6·48	6·62	39
4·50	4·70	4·90	5·09	5·28	5·45	5·62	5·78	5·94	6·08	6·23	6·36	6·49	6·61	6·74	40
4·60	4·80	5·00	5·19	5·38	5·54	5·70	5·86	6·03	6·18	6·34	6·48	6·61	6·73	6·86	41
4·70	4·90	5·10	5·29	5·48	5·63	5·78	5·94	6·11	6·28	6·45	6·59	6·73	6·85	6·97	42
4·80	5·00	5·20	5·39	5·58	5·72	5·86	6·02	6·20	6·38	6·56	6·70	6·85	6·97	7·08	43
4·89	5·09	5·30	5·49	5·68	5·81	5·94	6·10	6·28	6·47	6·67	6·81	6·97	7·09	7·19	44
4·98	5·18	5·39	5·58	5·78	5·90	6·02	6·18	6·37	6·57	6·77	6·92	7·09	7·21	7·30	45
5·07	5·27	5·48	5·67	5·87	5·98	6·10	6·26	6·45	6·67	6·87	7·03	7·21	7·32	7·41	46
5·16	5·36	5·57	5·76	5·96	6·06	6·18	6·34	6·54	6·76	6·97	7·14	7·33	7·43	7·52	47
5·25	5·45	5·66	5·85	6·05	6·14	6·26	6·42	6·62	6·85	7·07	7·25	7·45	7·54	7·63	48
5·34	5·54	5·75	5·94	6·14	6·22	6·34	6·50	6·71	6·94	7·17	7·36	7·56	7·65	7·74	49
5·43	5·63	5·84	6·03	6·23	6·30	6·38	6·58	6·79	7·03	7·27	7·47	7·67	7·76	7·85	50
5·52	5·72	5·94	6·13	6·33	6·41	6·50	6·70	6·91	7·14	7·37	7·57	7·77	7·86	7·96	51
5·61	5·81	6·03	6·23	6·43	6·52	6·62	6·81	7·03	7·25	7·47	7·67	7·87	7·96	8·07	52
5·70	5·90	6·12	6·33	6·53	6·63	6·74	6·93	7·15	7·36	7·57	7·77	7·96	8·06	8·18	53
5·78	5·98	6·21	6·42	6·63	6·74	6·86	7·04	7·27	7·47	7·67	7·87	8·05	8·16	8·29	54
5·86	6·06	6·30	6 51	6·73	6·85	6·98	7·16	7·39	7·58	7·77	7·97	8·14	8·25	8·40	55
5·94	6·14	6·39	6·60	6·82	6·96	7·10	7·27	7·50	7·69	7·87	8·07	8·23	8·35	8·51	56
6·02	6·22	6·48	6·69	6·91	7·06	7·22	7·39	7·61	7·79	7·97	8·16	8·32	8·45	8·61	57
6·10	6·30	6·57	6·78	7·00	7·16	7·33	7·50	7·72	7·89	8·07	8·25	8·41	8·55	8·71	58
6·18	6·38	6·66	6·87	7·09	7·26	7·44	7·62	7·82	7·99	8·17	8·34	8·50	8·65	8·81	59
6·26	6·50	6·75	6·96	7·18	7·36	7·55	7·73	7·92	8·09	8·27	8·43	8·59	8·75	8·91	60
6·37	6·61	6·85	7·06	7·27	7·46	7·65	7·83	8·02	8·19	8·37	8·53	8·69	8·85	9·01	61
6·48	6·71	6·95	7·16	7·36	7·56	7·75	7·93	8·11	8·28	8·47	8·63	8·79	8·95	9·11	62
6·59	6·81	7·05	7·25	7·45	7·65	7·85	8·03	8 21	8·38	8·56	8·73	8·88	9·05	9·21	63
6·70	6·91	7·15	7·34	7·54	7·74	7·94	8·13	8·30	8·47	8·65	8·83	8·97	9·15	9·31	64
6·81	7·00	7·24	7·43	7·63	7·83	8·03	8·22	8·39	8·56	8·75	8·92	9·07	9·25	9·42	65
6·92	7·10	7·33	7·52	7·72	7·92	8·12	8·31	8·49	8·66	8·84	9·02	9·17	9·35	9·52	66
7·02	7·19	7·42	7·61	7·81	8·01	8·21	8·40	8·58	8·75	8·94	9·12	9·26	9·45	9·62	67
7·12	7·30	7·51	7·70	7·90	8·10	8·30	8·49	8·68	8·85	9·04	9·21	9·37	9·55	9·72	68
7·22	7·40	7·60	7·79	7·99	8·19	8·39	8·58	8·77	8·95	9·14	9·31	9·47	9·65	9·82	69
7·32	7·50	7·69	7·88	8·08	8·28	8·48	8·67	8·87	9·05	9·24	9·41	9·59	9·75	9·92	70
7·42	7·60	7·78	7·98	8·18	8·37	8·57	8·76	8·97	9·17	9·36	9·53	9·71	9·87	10·02	71
7·51	7·69	7·87	8·07	8·28	8·46	8·66	8·85	9·07	9·29	9·48	9·65	9·83	9·99	10·12	72
7·61	7·79	7·97	8·17	8·38	8·55	8·74	8·94	9·17	9·40	9·60	9·77	9·94	10·11	10·22	73
7·70	7·88	8·06	8·26	8·47	8·64	8·82	9·03	9·26	9·52	9·71	9·88	10·06	10·23	10·32	74
7·80	7·98	8·16	8·36	8·57	8·73	8·90	9·12	9·35	9·63	9·82	9·99	10·17	10·35	10·43	75
7·89	8·07	8·25	8·46	8·67	8·82	8·98	9·21	0·44	9·74	9·93	10·11	10·28	10·47	10·53	76
7·99	8·16	8·34	8·55	8·77	8·91	9·06	9·30	9·53	9·85	10·04	10·22	10·40	10·59	10·63	77
8·08	8·26	8·44	8·65	8·87	9·00	9·14	9·39	9·62	9·96	10·16	10·33	10·51	10·71	10·73	78
8·18	8·35	8·53	8·74	8·96	9·09	9·22	9·47	9·71	10·07	10·26	10·44	10·63	10·83	10·84	79
8·27	8·44	8·62	8·84	9·06	9·18	9·30	9·55	9·80	10·19	10·37	10·55	10·75	10·85	10·94	80
8·37	8·54	8·72	8·93	9·15	9·28	9·41	9·65	9·90	10·27	10·45	10·63	10·83	10·93	11·03	81
8·46	8·63	8·81	9·02	9·24	9·37	9·41	9·75	9·99	10·35	10·53	10·71	10·91	11·00	11·13	82
8·56	8·73	8·91	9·11	9·33	9·47	9·62	9·84	10·08	10·39	10·61	10·79	10·99	11·08	11·22	83
8·65	8·82	9·00	9·20	9·42	9·56	9·72	9·94	10·18	10·49	10·69	10·87	11·07	11·15	11·31	84
8·75	8·92	9·09	9·29	9·51	9·65	9·82	10·04	10·27	10·58	10·77	10·95	11·15	11·23	11·41	85
8·85	9·01	9·18	9·38	9·60	9·74	9·92	10·13	10·36	10.67	10·84	11·03	11·23	11·30	11·50	86
8·94	9·11	9·27	9·47	9·67	9·84	10·02	10·23	10·45	10·76	10·91	11·10	11·30	11·38	11·60	87
9·04	9·20	9·36	9·56	9·75	9·93	10·13	10·33	10·54	10·87	10·98	11·17	11·37	11·45	11·69	88
9·13	9·30	9·45	9·65	9·83	10·03	10·23	10·43	10·63	10·90	11·05	11·24	11·44	11·53	11·79	89
9·23	9·39	9·55	9·74	9·93	10·13	10·33	10·53	10·73	10·93	11·13	11·32	11·51	11·70	11·89	90
9·33	9·49	9·65	9·83	10·02	10·23	10·42	10·62	10·82	11·02	11·22	11·41	11·60	11·80	11·99	91
9·43	9·58	9·74	9·93	10·11	10·32	10·51	10·71	10·92	11·11	11·32	11·51	11·69	11·89	12·08	92
9·53	9·68	9·84	10·02	10·21	10·41	10·61	10·81	11·01	11·21	11·41	11·60	11·79	11·99	12·18	93
9·63	9·78	9·93	10·12	10·30	10·50	10·70	10·90	11·11	11·30	11·50	11·69	11·89	12·08	12·27	94
9·73	9·87	10·03	10·21	10·39	10·60	10·79	10·99	11·20	11·39	11·59	11·79	11·98	12·18	12·37	95
9·82	9·97	10·12	10·30	10·49	10·69	10·89	11·09	11·29	11·49	11·68	11·88	12·08	12·27	12·46	96
9·91	10·07	10·22	10·40	10·58	10·78	10·98	11·18	11·39	11·58	11·78	11·97	12·17	12·36	12·56	97
10·01	10·16	10·31	10·49	10·68	10·88	11·08	11·27	11·48	11·67	11·87	12·07	12·27	12·46	12·64	98
10·11	10·25	10·41	10·59	10·77	10·97	11·17	11·37	11·57	11·76	11·96	12·16	12·36	12·55	12·74	99
10·20	10·35	10·50	10·68	10·86	11·06	11·26	11·46	11·66	11·86	12·06	12·25	12·45	12·64	12·84	100

DIMENSIONS OF PADDLE

Length of Stroke in Feet. Diam. of Cylinder in Inches.	Diameter of Paddle Shaft Journal.														
	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9
21	4·23	4·54	4·82	5·05	5·30	5·50	5·71	5·89	6·07	6·23	6·39	6·54	6·68	6·80	6·95
22	4·37	4·68	4·96	5·20	5·46	5·66	5·88	6·07	6·25	6·42	6·58	6·83	6·88	7·01	7·16
23	4·52	4·81	5·11	5·35	5·62	5·83	6·05	6·25	6·43	6·61	6·77	7·03	7·08	7·21	7·37
24	4·66	4·95	5·25	5·51	5·78	5·99	6·22	6·43	6·62	6·80	6·96	7·22	7·28	7·42	7·58
25	4·81	5·09	5·40	5·66	5·94	6·16	6·40	6·60	6·80	6·98	7·15	7·42	7·49	7·62	7·78
26	4·95	5·22	5·54	5·81	6·10	6·33	6·57	6·78	6·98	7·17	7·35	7·61	7·69	7·83	7·99
27	5·10	5·36	5·69	5·96	6·26	6·49	6·74	6·96	7·16	7·36	7·54	7·81	7·89	8·03	8·20
28	5·24	5·49	5·83	6·11	6·42	6·66	6·91	7·14	7·35	7·55	7·73	8·01	8·09	8·24	8·41
29	5·38	5·53	5·98	6·26	6·58	6·82	7·08	7·31	7·53	7·73	7·92	8·20	8·29	8·44	8·62
30	5·42	5·67	6·12	6·42	6·74	6·99	7·26	7·49	7·72	7·92	8·12	8·30	8·49	8·65	8·83
31	5·47	5·88	6·25	6·56	6·84	7·14	7·41	7·65	7·88	8·09	8·29	8·47	8·67	8·83	9·02
32	5·59	6·00	6·38	6·69	6·98	7·29	7·56	7·81	8·04	8·25	8·46	8·65	8·85	9·02	9·21
33	5·71	6·12	6·51	6·83	7·12	7·43	7·71	7·97	8·20	8·42	8·63	8·82	9·03	9·20	9·39
34	5·83	6·24	6·64	6·96	7·26	7·58	7·87	8·13	8·37	8·58	8·80	9·00	9·21	9·39	9·58
35	5·95	6·37	6·77	7·10	7·41	7·73	8·02	8·28	8·53	8·75	8·97	9·17	9·39	9·57	9·76
36	6·07	6·49	6·90	7·23	7·55	7·88	8·17	8·44	8·69	8·92	9·14	9·35	9·57	9·76	9·95
37	6·19	6·61	7·03	7·37	7·69	8·03	8·32	8·60	8·85	9·08	9·31	9·52	9·75	9·94	10·14
38	6·31	6·73	7·16	7·50	7·83	8·17	8·47	8·76	9·02	9·25	9·48	9·70	9·93	10·12	10·33
39	6·43	6·85	7·29	7·64	7·97	8·32	8·63	8·91	9·18	9·42	9·65	9·87	10·11	10·30	10·51
40	6·55	6·98	7·42	7·78	8·16	8·47	8·79	9·07	9·35	9·59	9·83	10·05	10·29	10·49	10·70
41	6·57	7·19	7·54	7·90	8·29	8·60	8·93	9·21	9·50	9·74	9·99	10·21	10·45	10·66	10·87
42	6·67	7·20	7·66	8·03	8·42	8·74	9·07	9·36	9·65	9·89	10·15	10·37	10·62	10·83	11·04
43	6·77	7·31	7·78	8·15	8·55	8·87	9·21	9·50	9·80	10·04	10·31	10·53	10·78	11·00	11·21
44	6·87	7·42	7·90	8·28	8·68	9·01	9·35	9·65	9·95	10·19	10·47	10·70	10·95	11·16	11·38
45	6·97	7·54	8·02	8·40	8·81	9·14	9·50	9·79	10·10	10·35	10·63	10·86	11·11	11·33	11·55
46	7·06	7·65	8·15	8·53	8·94	9·28	9·64	9·94	10·25	10·50	10·78	11·02	11·28	11·50	11·72
47	7·16	7·76	8·27	8·65	9·07	9·41	9·78	10·08	10·39	10·65	10·93	11·18	11·44	11·66	11·89
48	7·26	7·88	8·40	8·78	9·20	9·55	9·92	10·23	10·54	10·80	11·09	11·34	11·61	11·83	12·06
49	7·37	7·99	8·52	8·90	9·33	9·68	10·06	10·37	10·69	10·96	11·15	11·51	11·77	12·00	12·23
50	7·48	8·10	8·61	9·02	9·46	9·82	10·20	10·51	10·84	11·12	11·42	11·67	11·94	12·17	12·41
51	7·60	8·20	8·72	9·14	9·58	9·95	10·34	10·65	10·98	11·27	11·57	11·82	12·10	12·33	12·57
52	7·70	8·31	8·83	9·26	9·71	10·08	10·47	10·79	11·12	11·41	11·71	11·97	12·25	12·49	12·73
53	7·80	8·41	8·94	9·38	9·83	10·21	10·61	10·93	11·26	11·56	11·86	12·12	12·41	12·64	12·89
54	7·90	8·52	9·05	9·50	9·96	10·34	10·74	11·06	11·40	11·70	12·00	12·27	12·56	12·80	13·05
55	8·00	8·62	9·16	9·61	10·08	10·47	10·88	11·20	11·54	11·85	12·15	12·42	12·72	12·96	13·21
56	8·09	8·73	9·27	9·73	10·21	10·60	11·01	11·33	11·69	11·99	12·29	12·57	12·87	13·15	13·37
57	8·19	8·84	9·39	9·85	10·33	10·73	11·15	11·47	11·83	12·14	12·44	12·72	13·03	13·31	13·53
58	8·29	8·94	9·50	9·97	10·45	10·86	11·28	11·61	12·97	12·28	12·58	12·87	13·18	13·47	13·69
59	8·39	9·05	9·61	10·08	10·58	10·99	11·42	11·75	12·11	12·42	12·72	13·02	13·33	13·62	13·85
60	8·49	9·15	9·72	10·20	10·70	11·12	11·55	11·89	12·25	12·56	12·89	13·17	13·48	13·74	14·02
61	8·58	9·25	9·82	10·30	10·79	11·23	11·67	12·02	12·38	12·70	13·03	13·31	13·63	13·89	14·17
62	8·67	9·35	9·93	10·40	10·89	11·34	11·79	12·14	12·51	12·83	13·17	13·45	13·77	14·04	14·32
63	8·76	9·45	10·03	10·50	10·98	11·45	11·91	12·27	12·65	12·97	13·31	13·59	13·92	14·19	14·47
64	8·86	9·55	10·14	10·60	11·08	11·56	12·03	12·39	12·78	13·10	13·45	13·73	14·06	14·34	14·62
65	8·95	9·65	10·24	10·70	11·17	11·67	12·16	12·52	12·91	13·24	13·59	13·87	14·21	14·49	14·77
66	9·04	9·74	10·35	10·79	11·27	11·78	12·28	12·64	13·04	13·37	13·73	14·02	14·35	14·64	14·93
67	9·13	9·84	10·45	10·89	11·36	11·89	12·40	12·77	13·17	13·51	13·87	14·16	14·50	14·79	15·08
68	9·22	9·94	10·56	10·99	11·45	11·99	12·52	12·89	13·30	13·65	14·01	14·30	14·64	14·94	15·23
69	9·31	10·04	10·66	11·09	11·54	12·10	12·64	13·02	13·43	13·78	14·15	14·45	14·79	15·09	15·39
70	9·41	10·14	10·77	11·19	11·64	12·20	12·77	13·16	13·57	13·92	14·29	14·60	14·94	15·23	15·54
71	9·50	10·23	10·87	11·30	11·77	12·32	12·89	13·28	13·70	14·05	14·42	14·74	15·08	15·37	15·68
72	9·59	10·33	10·97	11·41	11·90	12·44	13·01	13·40	13·82	14·18	14·55	14·88	15·22	15·51	15·83
73	9·67	10·42	11·07	11·52	12·03	12·56	13·13	13·52	13·95	14·31	14·69	15·02	15·36	15·65	15·97
74	9·76	10·52	11·17	11·62	12·16	12·67	13·25	13·64	14·07	14·44	14·82	15·15	15·50	15·79	16·12
75	9·85	10·61	11·27	11·73	12·29	12·79	13·37	13·76	14·20	14·57	14·95	15·29	15·64	15·93	16·26
76	9·93	10·71	11·36	11·83	12·43	12·91	13·49	13·89	14·32	14·70	15·09	15·43	15·78	16·07	16·41
77	10·02	10·80	11·46	11·94	12·56	13·03	13·61	14·01	14·45	14·83	15·22	15·56	15·92	16·21	16·55
78	10·11	10·89	11·56	12·05	12·69	13·15	13·73	14·13	14·57	14·96	15·35	15·69	16·06	16·35	16·70
79	10·20	10·99	11·66	12·16	12·83	13·26	13·85	14·26	14·70	15·09	15·48	15·82	16·20	16·49	16·84
80	10·29	11·08	11·76	12·27	12·96	13·38	13·96	14·38	14·84	15·22	15·62	15·97	16·33	16·63	16·98
81	10·37	11·17	11·86	12·38	13·06	13·49	14·07	14·50	14·96	15·34	15·75	16·10	16·46	16·74	17·12
82	10·46	11·26	11·96	12·49	13·17	13·61	14·19	14·62	15·08	15·46	15·88	16·23	16·59	16·88	17·26
83	10·54	11·35	12·06	12·60	13·27	13·73	14·30	14·73	15·20	15·59	16·00	16·36	16·73	17·01	17·40
84	10·63	11·44	12·15	12·71	13·38	13·84	14·42	14·85	15·32	15·71	16·13	16·49	16·86	17·14	17·54
85	10·71	11·52	12·25	12·81	13·48	13·95	14·53	14·97	15·44	15·84	16·25	16·61	17·00	17·28	17·68
86	10·80	11·61	12·35	12·92	13·59	14·07	14·65	15·09	15·56	15·96	16·38	16·74	17·13	17·42	17·82
87	10·88	11·70	12·44	13·03	13·69	14·18	14·76	15·21	15·68	16·09	16·50	16·87	17·27	17·56	17·96
88	10·97	11·79	12·54	13·14	13·80	14·30	14·88	15·32	15·80	16·21	16·63	17·00	17·40	17·70	18·10
89	11·05	11·88	12·64	13·24	13·90	14·42	14·99	15·44	15·92	16·33	16·75	17·13	17·53	17·84	18·24
90	11·13	11·99	12·74	13·34	14·00	14·54	15·10	15·56	16·05	16·45	16·89	17·26	17·66	18·01	18·37
91	11·21	12·08	12·83	13·40	14·11	14·64	15·21	15·67	16·17	16·57	17·02	17·39	17·79	18·14	18·51
92	11·29	12·17	12·92	13·47	14·21	14·75	15·32	15·79	16·28	16·69	17·14	17·51	17·92	18·27	18·64
93	11·37	12·26	13·01	13·53	14·32	14·85	15·43	15·90	16·40	16·81	17·26	17·64	18·05	18·40	18·78
94	11·45	12·34	13·10	13·60	14·42	14·96	15·54	16·02	16·51	16·93	17·38	17·76	18·18	18·53	18·91
95	11·53	12·43	13·20	13·66	14·53	15·07	15·65	16·13	16·63	17·05	17·51	17·88	18·31	18·66	19·05
96	11·61	12·51	13·29	13·73	14·63	15·18	15·76	16·25	16·74	17·18	17·63	18·01	18·44	18·79	19·18
97	11·69	12·60	13·38	13·79	14·74	15·29	15·87	16·36	16·86	17·30	17·75	18·14	18·57	18·92	19·32
98	11·77	12·68	13·47	13·86	14·84	15·39	15·98	16·48	16·97	17·42	17·87	18·26	18·70	19·05	19·45
99	11·85	12·77	13·56	13·92	14·94	15·50	16·09	16·59	17·09	17·54	18·00	18·39	18·83	19·18	19·59
100	11·93	12·85	13·66	14·01	15·04	15·61	16·20	16·71	17·22	17·66	18·12	18·52	18·95	19·32	19·71

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LENGTH of Paddle Shaft Journal.															Diam. of Cylinder in Inches.
2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	Length of Stroke in Feet
5·37	5·69	6·03	6·31	6·62	6·87	7·14	7·36	7·59	7·78	7·99	8·18	8·36	8·55	8·69	21
5·53	5·85	6·21	6·50	6·82	7·08	7·35	7·59	7·82	8·02	8·23	8·44	8·61	8·83	8·96	22
5·68	6·02	6·39	6·69	7·02	7·29	7·57	7·81	8·05	8·25	8·47	8·70	8·86	9·10	9·23	23
5·84	6·19	6·57	6·88	7·22	7·50	7·78	8·04	8·28	8·49	8·71	8·96	9·11	9·36	9·50	24
5·99	6·36	6·75	7·07	7·42	7·70	8·00	8·26	8·51	8·72	8·95	9·22	9·36	9·61	9·76	25
6·15	6·53	6·93	7·26	7·62	7·91	8·21	8·48	8·74	8·96	9·19	9·48	9·61	9·85	10·02	26
6·30	6·70	7·11	7·45	7·82	8·11	8·43	8·70	8·97	9·19	9·43	9·73	9·86	10·10	10·28	27
6·46	6·87	7·29	7·64	8·02	8·32	8·64	8·92	9·20	9·43	9·67	9·98	10·11	10·36	10·54	28
6·61	7·04	7·47	7·83	8·22	8·53	8·86	9·14	9·43	9·66	9·91	10·23	10·36	10·61	10·80	29
6·77	7·21	7·65	8·02	8·42	8·74	9·07	9·36	9·65	9·90	10·15	10·48	10·61	10·82	11·04	30
6·92	7·37	7·82	8·19	8·60	8·93	9·27	9·56	9·86	10·11	10·37	10·70	10·84	11·05	11·28	31
7·06	7·52	7·98	8·36	8·78	9·11	9·47	9·76	10·06	10·32	10·58	10·91	11·07	11·28	11·52	32
7·20	7·67	8·14	8·53	8·96	9·30	9·56	9·96	10·27	10·53	10·79	11·12	11·30	11·51	11·76	33
7·34	7·82	8·30	8·70	9·14	9·48	5·75	10·15	10·47	10·74	11·00	11·33	11·53	11·74	11·99	34
7·48	7·97	8·46	8·87	9·31	9·67	9·94	10·35	10·68	10·95	11·22	11·54	11·76	11·97	12·22	35
7·62	8·12	8·63	9·04	9·49	9·85	10·13	10·55	10·88	11·16	11·43	11·75	11·98	12·20	12·45	36
7·76	8·27	8·79	9·21	9·67	10·04	10·32	10·74	11·09	11·37	11·64	11·96	12·20	12·43	12·68	37
7·90	8·42	8·95	9·38	9·85	10·22	10·51	10·94	11·29	11·58	11·86	12·17	12·42	12·66	12·91	38
8·05	8·57	9·11	9·55	10·03	10·41	10·80	11·14	11·49	11·79	12·07	12·38	12·64	12·89	13·14	39
8·19	8·72	9·27	9·72	10·20	10·58	10·99	11·34	11·69	11·99	12·29	12·57	12·86	13·11	13·37	40
8·32	8·86	9·42	9·88	10·37	10·75	11·17	11·53	11·88	12·19	12·49	12·77	13·07	13·33	13·59	41
8·44	9·00	9·57	10·03	10·54	10·92	11·34	11·71	12·06	12·39	12·69	12·98	13·28	13·54	13·81	42
8·56	9·13	9·72	10·18	10·70	11·09	11·52	11·89	12·25	12·58	12·88	13·18	13·49	13·75	14·03	43
8·68	9·27	9·87	10·34	10·86	11·26	11·69	12·07	12·43	12·77	13·08	13·38	13·70	13·96	14·25	44
8·80	9·40	10·02	10·49	11·02	11·43	11·87	12·25	12·62	12·96	13·28	13·58	13·91	14·17	14·46	45
8·92	9·54	10·17	10·64	11·18	11·59	12·04	12·43	12·80	13·15	13·47	13·78	14·12	14·38	14·67	46
9·04	9·67	10·32	10·79	11·34	11·76	12·22	12·61	12·99	13·34	13·67	13·98	14·32	14·59	14·88	47
9·16	9·81	10·47	10·94	11·50	11·93	12·39	12·79	13·17	13·53	13·87	14·18	14·52	14·80	15·09	48
9·28	9·94	10·62	11·10	11·66	12·10	12·57	12·97	13·36	13·72	14·07	14·38	14·72	15·01	15·30	49
9·40	10·08	10·76	11·26	11·82	12·27	12·75	13·15	13·55	13·91	14·27	14·58	14·92	15·22	15·51	50
9·53	10·21	10·90	11·41	11·98	12·43	12·92	13·32	13·73	14·09	14·46	14·77	15·12	15·42	15·72	51
9·65	10·34	11·04	11·56	12·13	12·59	13·09	13·50	13·90	14·27	14·64	14·96	15·32	15·62	15·92	52
9·77	10·47	11·18	11·71	12·29	12·75	13·26	13·67	14·08	14·45	14·83	15·15	15·52	15·82	16·12	53
9·89	10·60	11·32	11·86	12·44	12·91	13·43	13·85	14·25	14·63	15·02	15·34	15·71	16·02	16·32	54
10·01	10·73	11·46	12·01	12·60	13·07	13·60	14·02	14·43	14·81	15·20	15·53	15·90	16·22	16·52	55
10·13	10·86	11·60	12·16	12·75	13·23	13·77	14·19	14·60	14·99	15·39	15·72	16·09	16·42	16·72	56
10·25	10·99	11·74	12·31	12·91	13·39	13·94	14·36	14·78	15·17	15·57	15·91	16·28	16·61	16·92	57
10·37	11·13	11·88	12·46	13·06	13·55	14·11	14·53	14·95	15·35	15·76	16·10	16·47	16·80	17·12	58
10·49	11·25	12·02	12·61	13·21	13·71	14·28	14·70	15·13	15·53	15·94	16·29	16·66	16·99	17·32	59
10·61	11·37	12·15	12·75	13·37	13·87	14·44	14·86	15·31	15·71	16·11	16·47	16·85	17·18	17·52	60
10·72	11·49	12·28	12·88	13·49	14·01	14·60	15·02	15·48	15·88	16·29	16·65	17·04	17·37	17·71	61
10·84	11·62	12·41	13·00	13·61	14·15	14·76	15·18	15·64	16·05	16·47	16·83	17·23	17·56	17·90	62
10·95	11·74	12·54	13·13	13·73	14·29	14·91	15·34	15·81	16·22	16·65	17·01	17·41	17·75	18·09	63
11·07	11·86	12·67	13·25	13·85	14·42	15·06	15·50	15·97	16·39	16·83	17·19	17·59	17·94	18·28	64
11·18	11·98	12·80	13·38	13·97	14·56	15·21	15·66	16·14	16·56	17·01	17·37	17·77	18·13	18·47	65
11·30	12·11	12·93	13·50	14·09	14·70	15·36	15·82	16·30	16·73	17·18	17·55	17·95	18·32	18·66	66
11·41	12·23	13·06	13·63	14·21	14·83	15·51	15·98	16·47	16·90	17·35	17·73	18·13	18·50	18·85	67
11·53	12·35	13·19	13·75	14·33	14·97	15·66	16·14	16·63	17·07	17·52	17·91	18·31	18·68	19·04	68
11·64	12·47	13·32	13·88	14·45	15·11	15·81	16·30	16·80	17·24	17·69	18·09	18·49	18·86	19·23	69
11·76	12·60	13·46	14·01	14·55	15·25	15·96	16·46	16·96	17·41	17·86	18·26	18·67	19·04	19·42	70
11·87	12·72	13·59	14·15	14·72	15·40	16·11	16·61	17·12	17·57	18·03	18·44	18·85	19·22	19·60	71
11·98	12·84	13·71	14·29	14·88	15·56	16·26	16·77	17·28	17·74	18·20	18·61	19·03	19·40	19·78	72
12·09	12·95	13·84	14·43	15·05	15·71	16·41	16·92	17·44	17·90	18·37	18·78	19·21	19·58	19·96	73
12·20	13·07	13·96	14·58	15·21	15·87	16·56	17·08	17·60	18·06	18·54	18·95	19·39	19·76	20·14	74
12·31	13·18	14·08	14·72	15·38	16·02	16·71	17·23	17·76	18·22	18·71	19·12	19·56	19·94	20·32	75
12·42	13·30	14·20	14·87	15·54	16·18	16·86	17·39	17·92	18·38	18·87	19·29	19·73	20·12	20·50	76
12·53	13·41	14·32	15·01	15·71	16·33	17·01	17·54	18·08	18·54	19·03	19·46	19·90	20·30	20·68	77
12·64	13·53	14·44	15·15	15·87	16·49	17·16	17·70	18·24	18·70	19·19	19·63	20·07	20·47	20·86	78
12·75	13·64	14·56	15·29	16·04	16·65	17·31	17·85	18·40	18·86	19·35	19·80	20·24	20·64	21·04	79
12·86	13·76	14·70	15·44	16·20	16·81	17·45	18·00	18·55	19·03	19·52	19·97	20·41	20·81	21·22	80
12·97	13·88	14·83	15·57	16·33	16·95	17·59	18·15	18·71	19·19	19·68	20·14	20·58	20·99	21·40	81
13·07	13·99	14·95	15·70	16·46	17·08	17·73	18·29	18·86	19·35	19·84	20·31	20·75	21·16	21·58	82
13·18	14·11	15·07	15·82	16·59	17·22	17·88	18·43	19·01	19·50	20·00	20·47	20·92	21·33	21·76	83
13·28	14·22	15·19	15·95	16·72	17·35	18·03	18·58	19·16	19·65	20·16	20·63	21·09	21·50	21·94	84
13·39	14·34	15·31	16·07	16·85	17·49	18·17	18·72	19·31	19·80	20·32	20·79	21·26	21·67	22·11	85
13·49	14·45	15·43	16·20	16·98	17·62	18·31	18·87	19·46	19·95	20·48	20·95	21·43	21·84	22·28	86
13·60	14·57	15·55	16·32	17·11	17·75	18·45	19·02	19·61	20·10	20·64	21·11	21·59	22·01	22·45	87
13·70	14·68	15·67	16·45	17·24	17·89	18·59	19·16	19·75	20·25	20·80	21·27	21·75	22·18	22·62	88
13·81	14·80	15·79	16·58	17·37	18·02	18·74	19·31	19·90	20·40	20·96	21·43	21·91	22·35	22·79	89
13·91	14·91	15·92	16·76	17·50	18·15	18·87	19·47	20·06	20·56	21·11	21·59	22·07	22·52	22·96	90
14·01	15·02	16·04	16·83	17·63	18·29	19·01	19·61	20·21	20·72	21·27	21·75	22·24	22·69	23·13	91
14·11	15·14	16·15	16·95	17·76	18·42	19·14	19·75	20·36	20·87	21·42	21·91	22·40	22·86	23·30	92
14·21	15·25	16·27	17·07	17·89	18·56	19·27	19·89	20·50	21·02	21·58	22·07	22·57	23·03	23·47	93
14·31	15·36	16·38	17·19	18·02	18·69	19·40	20·03	20·65	21·17	21·73	22·23	22·73	23·19	23·64	94
14·41	15·47	16·50	17·31	18·15	18·83	19·54	20·17	20·79	21·32	21·88	22·39	22·89	23·35	23·81	95
14·51	15·59	16·61	17·43	18·28	18·96	19·67	20·31	20·94	21·47	21·03	22·54	23·05	23·51	23·98	96
14·61	15·70	16·73	17·55	18·41	19·10	19·81	20·45	21·08	21·62	21·18	22·69	23·21	23·67	24·15	97
14·71	15·82	16·84	17·67	18·54	19·23	19·95	20·59	21·23	21·77	21·33	22·84	23·37	23·83	24·32	98
14·81	15·93	16·96	17·79	18·67	19·37	20·09	20·73	21·37	21·92	21·48	22·99	23·53	23·99	24·48	99
14·91	16·08	17·07	17·92	18·80	19·52	20·25	20·87	21·52	22·07	22·65	23·15	23·69	24·15	24·64	100

Diameter of Cylinder in Inches.	Crank-pin Journal.		Dimensions of the several Parts of Crosshead.								DIMENSIONS OF THE SEVERAL					
	Diameter of Crank-pin Journal.	Length of Crank-pin Journal.	Breadth of Eye.	Depth of Eye.	Diameter of Journal.	Length of Journal.	Thickness of Web at Middle.	Breadth of Web at Middle.	Thickness of Web at Journal.	Breadth of Web at Journal.	Diameter of Piston Rod.	Length of Part in Piston.	Major Diameter of Part in Crosshead.	Minor Diameter of Part in Crosshead.	Major Diameter of Part in Piston.	Minor Diameter of Part in Piston.
23	3·24	3·68	·95	6·61	1·97	2·20	1·66	6·16	1·40	2·32	2·30	4·60	2·18	2·07	3·22	2·64
24	3·38	3·84	·99	6·90	2·05	2·29	1·73	6·42	1·47	2·42	2·40	4·80	2·28	2·16	3·36	2·76
25	3·52	4·00	1·03	7·19	2·14	2·39	1·81	6·68	1·53	2·52	2·50	5·00	2·37	2·25	3·50	2·87
26	3·66	4·16	1·07	7·48	2·22	2·48	1·88	6·95	1·59	2·63	2·60	5·20	2·47	2·34	3·64	2·99
27	3·80	4·32	1·11	7·76	2·31	2·58	1·95	7·22	1·65	2·73	2·70	5·40	2·56	2·43	3·78	3·11
28	3·94	4·48	1·15	8·05	2·39	2·67	2·02	7·49	1·71	2·83	2·80	5·60	2·66	2·52	3·92	3·22
29	4·08	4·64	1·19	8·33	2·48	2·77	2·10	7·75	1·77	2·93	2·90	5·80	2·75	2·61	4·06	3·34
30	4·26	4·80	1·24	8·61	2·57	2·86	2·17	8·02	1·83	3·03	3·00	6·00	2·85	2·70	4·20	3·45
31	4·40	4·96	1·28	8·89	2·65	2·96	2·24	8·29	1·89	3·13	3·10	6·20	2·94	2·79	4·34	3·57
32	4·54	5·12	1·32	9·18	2·74	3·06	2·31	8·56	1·95	3·23	3·20	6·40	3·04	2·88	4·48	3·68
33	4·68	5·28	1·36	9·46	2·82	3·16	2.38	8·83	2·01	3·33	3·30	6·60	3·13	2·97	4·62	3·80
34	4·83	5·44	1·40	9·72	2·92	3·26	2·45	9·11	2·07	3·43	3·4	6·8	3·23	3·06	4·76	3·91
35	4·97	5·60	1·44	10·01	3·01	3·40	2·52	9·38	2·13	3·53	3·5	7·0	3·32	3·15	4·90	4·02
36	5·11	5·76	1·48	10·30	3·09	3·49	2·59	9·65	2·19	3·63	3·6	7·2	3·42	3·24	5·04	4·14
37	5·26	5·92	1·52	10·59	3·18	3·59	2·66	9·92	2·25	3·73	3·7	7·4	3·51	3·33	5·18	4·25
38	5·40	6·08	1·56	10·88	3·26	3·69	2·73	10·18	2·31	3·83	3·8	7·6	3·61	3·42	5·32	4·36
39	5·54	6·24	1·60	11·17	3·35	3·78	2·81	10·45	2·37	3·93	3·9	7·8	3·70	3·51	5·46	4·48
40	5·69	6·40	1·65	11·46	3·44	3·88	2·88	10·72	2·44	4·04	4·0	8·0	3·80	3·60	5·60	4·59
41	5·83	6·52	1·69	11·75	3·52	3·98	2·95	10·99	2·50	4·14	4·1	8·2	3·89	3·69	5·74	4·70
42	5·97	6·68	1·73	12·03	3·61	4·07	3·02	11·26	2·56	4·24	4·2	8·4	3·99	3·78	5·88	4·82
43	6·11	6·84	1·77	12·32	3·70	4·17	3·09	11·53	2·62	4·34	4·3	8·6	4·08	3·87	6·02	4·93
44	6.25	7·00	1·81	12·61	3·78	4·27	3·16	11·80	2·68	4·44	4·4	8·8	4·18	3·96	6·16	5·05
45	6·39	7·16	1·85	12·90	3·87	4·36	3·24	12·07	2·74	4·54	4·5	9·0	4·27	4·05	6·30	5·17
46	6·54	7·32	1·89	13·19	3·95	4·46	3·31	12·33	2·80	4·64	4·6	9·2	4·37	4·14	6·44	5·28
47	6·68	7·47	1·93	13·48	4·04	4·55	3·38	12·60	2·86	4·74	4·7	9·4	4·46	4·23	6·58	5·39
48	6·82	7·63	1·98	13.77	4·12	4·65	3·45	12·87	2·93	4·84	4·8	9·6	4·56	4·32	6·72	5·51
49	6·96	7·79	2·03	14·05	4·21	4·75	3·52	13·14	2·99	4·94	4·9	9·8	4·65	4·41	6·86	5·62
50	7·11	7·95	2·07	14·34	4·29	4·84	3·59	13·41	3·05	5·05	5·0	10·0	4·75	4·50	7·00	5·74
51	7·25	8·11	2·11	14·62	4·38	4·94	3·67	13·67	3·11	5·15	5·1	10·2	4·84	4·59	7·14	5·85
52	7·39	8·27	2·15	14·91	4·46	5·04	3·74	13·94	3·17	5·25	5·2	10·4	4·94	4·68	7·28	5·97
53	7·53	8.43	2·19	15·20	4·55	5·13	3·81	14·21	3·24	5·35	5·3	10·6	5·04	4·77	7·42	6·09
54	7.67	8·59	2·23	15·49	4·64	5·24	3·88	14·48	3·30	5·45	5·4	10·8	5·13	4·86	7·56	6·21
55	7·81	8·75	2·27	15·78	4·73	5·34	3·96	14·74	3·36	5·55	5·5	11·0	5·23	4·95	7·70	6·33
56	7·95	8·91	2·31	16·07	4·81	5·43	4·03	15·01	3·42	5·65	5·6	11·2	5·32	5·04	7·84	6·44
57	8·09	9·07	2·35	16·36	4·90	5·53	4·10	15·28	3·49	5·75	5·7	11·4	5·42	5·13	7·98	6·56
58	8·24	9·23	2·40	16·65	4·98	5·62	4·17	15·55	3·55	5·85	5·8	11·6	5·51	5·22	8·12	6·67
59	8·38	9·39	2·44	16·94	5·07	5·72	4·24	15·82	3·61	5·95	5·9	11·8	5·61	5·31	8·26	6·79
60	8·52	9·54	2·48	17·22	5·15	5·82	4·31	16·09	3·67	6·06	6·0	12·0	5·70	5·40	8·40	6·90
61	8·66	9·70	2·52	17·51	5·24	5·91	4·38	16·36	3·74	6·16	6·1	12·2	5·80	5·49	8·54	7·02
62	8·80	9·86	2·56	17·80	5·33	6·00	4·45	16·62	3·80	6·26	6·2	12·4	5·89	5·58	8·68	7·13
63	8·95	10·02	2·60	18·09	5·41	6·10	4·53	16·88	3·86	6·36	6·3	12·6	5·99	5·67	8·82	7·25
64	9·09	10·18	2·64	18·37	5·50	6·19	4·60	17·15	3·93	6·46	6·4	12·8	6·08	5·76	8·96	7·36
65	9·23	10·34	2·68	18·66	5·58	6·29	4·67	17·42	3·99	6·56	6·5	13·0	6·18	5·85	9·10	7·48
66	9·37	10·50	2·72	18·95	5·67	6·39	4·74	17·69	4·05	6·66	6·6	13·2	6·27	5·94	9·24	7·59
67	9·51	10·66	2·76	19·23	5·75	6·48	4·81	17·96	4·11	6·76	6·7	13·4	6·37	6·03	9·38	7·71
68	9·65	10·82	2·80	19·51	5·84	6·58	4·88	18·23	4·17	6·86	6·8	13·6	6·46	6·12	9·52	7·82
69	9·80	10·98	2·84	19·80	5·92	6·67	4·95	18·49	4·24	6·96	6·9	13·8	6·56	6·21	9·66	7·93
70	9·94	11·13	2·88	20·08	6·01	6·77	5·02	18·76	4·30	7·07	7·0	14·0	6·65	6·30	9·80	8·05
71	10·08	11·29	2·93	20·36	6·10	6·87	5·10	19·03	4·36	7·17	7·1	14·2	6·75	6·39	9·94	8·16
72	10·22	11·45	2·97	20·64	6·18	6·97	5·17	19·30	4·43	7·27	7·2	14·4	6·84	6·48	10·08	8·28
73	10·36	11·61	3·01	20·92	6·27	7·06	5·25	19·56	4·49	7·37	7·3	14·6	6·94	6·57	10·22	8·39
74	10·50	11·77	3·05	21·21	6·35	7·16	5·32	19·83	4·55	7·47	7·4	14·8	7·03	6·66	10·36	8·51
75	10·65	11·93	3·09	21·49	6·44	7·26	5·40	20·09	4·62	7·57	7·5	15·0	7·13	6·75	10·50	8·62
76	10·79	12·08	3·13	21·74	6·54	7·37	5·47	20·35	4·64	7·68	7·6	15·2	7·22	6·84	10·64	8·74
77	10·93	12·24	3·17	22·03	6·62	7·47	5·54	20·62	4·70	7·78	7·7	15·4	7·31	6·93	10·78	8·85
78	11·07	12·40	3·21	22·31	6·71	7·56	5·61	20·89	4·76	7·88	7·8	15·6	7·41	7·02	10·92	8·97
79	11·22	12·56	3·25	22·59	6·79	7·66	5·68	21·16	4·82	7·98	7·9	15·8	7·50	7·11	11·06	9·08
80	11·36	12·72	3·29	22·87	6·88	7·75	5·76	21·43	4·88	8·08	8·0	16·0	7·60	7·20	11·20	9·20
81	11·50	12·88	3·34	23·16	6·96	7·85	5·83	21·71	4·94	8·18	8·1	16·2	7·69	7·29	11·34	9·31
82	11·64	13·04	3·39	23·45	7·05	7·94	5·90	21·98	5·00	8·28	8·2	16·4	7·79	7·38	11·48	9·43
83	11·78	13·19	3·44	23·73	7·14	8·04	5·97	22·25	5·07	8·38	8·3	16·6	7·88	7·47	11·62	9·54
84	11·93	13·35	3·48	24·02	7·22	8·14	6·04	22·52	5·13	8·48	8·4	16·8	7·98	7·56	11·76	9·66
85	12·07	13·51	3·52	24·30	7·31	8·23	6·11	22·79	5·19	8·58	8·5	17·0	8·08	7·65	11·90	9·77
86	12·21	13·67	3·56	24·59	7·40	8·33	6·18	23·06	5·25	8·68	8·6	17·2	8·18	7·74	12·04	9·89
87	12·36	13·83	3·60	24·87	7·48	8·42	6·26	23·33	5·31	8·78	8·7	17·4	8·27	7·83	12·18	10·00
88	12·50	13·99	3·64	25·16	7·57	8·52	6·33	23·60	5·37	8·88	8·8	17·6	8·37	7·92	12·32	10·12
89	12·64	14·15	3·68	25·44	7·65	8·61	6·40	23·88	5·43	8·98	8·9	17·8	8·46	8·01	12·46	10·23
90	12·79	14·30	3·72	25·72	7·74	8·71	6·48	24·15	5·49	9·09	9·0	18·0	8·56	8·10	12·60	10·34
91	12·93	14·46	3·76	26·01	7·82	8·80	6·55	24·41	5·55	9·19	9·1	18·2	8·65	8·19	12·74	10·46
92	13·07	14·62	3·80	26·30	7·91	8·90	6·62	24·68	5·61	9·29	9·2	18·4	8·75	8·28	12·88	10·57
93	13·21	14·78	3·84	26·58	8·00	9·00	6·69	24·94	5·67	9·39	9·3	18·6	8·84	8·37	13·02	10·69
94	13·35	14·94	3·88	26·87	8·08	9·09	6·76	25·20	5·73	9·49	9·4	18·8	8·94	8·46	13·16	10·80
95	13·49	15·10	3·92	27·15	8·17	9·19	6·84	25·47	5·79	9·59	9·5	19·0	9·03	8·55	13·30	10·92
96	13·64	15·26	3·96	27·43	8·25	9·29	6·91	25·73	5·85	9·69	9·6	19·2	9·12	8.64	13·44	11·03
97	13·78	15·42	4·00	27·72	8·34	9·38	6·98	26·00	5·92	9·79	9·7	19·4	9·22	8·73	13·58	11·15
98	13·92	15·58	4·04	28·01	8·43	9·48	7·05	26·27	5·98	9·89	9·8	19·6	9·32	8·82	13·72	11·26
99	14·06	15·74	4·08	28·29	8·51	9·57	7·13	26·53	6·04	9·99	9·9	19·8	9·41	8·91	13·86	11·37
100	14·20	15·90	4·12	28·58	8·59	9·67	7·22	26·79	6·10	10·10	10·0	20·0	9·50	9·00	14·00	11·49

PARTS OF PISTON ROD.				Dimensions of the several Parts of the Connecting Rod.											
Depth of Gibs and Cutter through Crosshead.	Thickness of Gibs and Cutter through Crosshead.	Depth of Cutter through Piston.	Thickness of Cutter through Piston.	Diameter of Connecting Rod at Ends.	Major Diameter of Part in Crosstail.	Minor Diameter of Part in Crosstail.	Breadth of Butt.	Thickness of Butt.	Mean Thickness of Strap at Cutter.	Mean Thickness of Strap above Cutter.	Distance of Cutter from End of Strap.	Breadth of Gibs and Cutter through Crosstail.	Breadth of Gibs and Cutter through Butt.	Thickness of Gibs and Cutter through Butt.	Diam. of Cylinder in Inches.
2·42	·48	1·95	·80	2·18	2·25	2·07	3·58	2·87	·99	·74	1·11	2·41	2·53	·64	23
2·53	·50	2·04	·84	2·28	2·35	2·16	3·73	3·00	1·03	·77	1·16	2·52	2·64	·67	24
2·63	·52	2·12	·87	2·37	2·45	2·25	3·89	3·12	1·07	·80	1·20	2·62	2·75	·70	25
2·74	·54	2·21	·90	2·47	2·55	2·34	4·05	3·25	1·11	·84	1·25	2·73	2·86	·73	26
2·84	·57	2·29	·94	2·56	2·64	2·43	4·20	3·37	1·15	·87	1·30	2·83	2·97	·76	27
2·95	·59	2·38	·97	2·66	2·74	2·52	4·36	3·50	1·19	·90	1·35	2·94	3·08	·79	28
3·05	·61	2·46	1·00	2·75	2·84	2·61	4·51	3·62	1·23	·93	1·39	3·04	3·19	·81	29
3·16	·63	2·55	1·04	2·85	2·93	2·70	4·67	3·75	1·28	·97	1·44	3·15	3·30	·83	30
3·26	·65	2·63	1·07	2·94	3·03	2·79	4·83	3·87	1·33	1·00	1·49	3·25	3·41	·86	31
3·37	·67	2·72	1·10	3·03	3·13	2·88	4·99	4·00	1·37	1·03	1·53	3·36	3·52	·89	32
3·47	·69	2·80	1·14	3·13	3·22	2·97	5·15	4·12	1·41	1·06	1·58	3·46	3·63	·92	33
3·57	·71	2·89	1·19	3·23	3·33	3·06	5·30	4·25	1·46	1·09	1·65	3·57	3·74	·99	34
3·67	·73	2·97	1·22	3·33	3·42	3·15	5·46	4·37	1·50	1·12	1·70	3·67	3·85	1·02	35
3·78	·75	3·06	1·26	3·42	3·52	3·24	5·61	4·50	1·54	1·15	1·75	3·78	3·96	1·05	36
3·88	·78	3·14	1·29	3·52	3·62	3·33	5·77	4·62	1·59	1·19	1·80	3·88	4·07	1·08	37
3·99	·80	3·23	1·33	3·61	3·72	3·42	5·92	4·75	1·63	1·22	1·84	3·99	4·18	1·11	38
4·09	·82	3·31	1·36	3·71	3·81	3·51	6·08	4·87	1·67	1·25	1·89	4·09	4·29	1·14	39
4·20	·84	3·40	1·40	3·80	3·91	3·60	6·23	5·00	1·72	1·28	1·94	4·20	4·40	1·17	40
4·30	·86	3·48	1·43	3·90	4·01	3·69	6·38	5·12	1·76	1·32	1·99	4·31	4·51	1·20	41
4·41	·89	3·57	1·47	3·99	4·11	3·78	6·54	5·25	1·80	1·35	2·03	4·41	4·62	1·22	42
4·51	·91	3·65	1·50	4·09	4·21	3·87	6·69	5·37	1·85	1·38	2·07	4·52	4·73	1·25	43
4·62	·93	3·74	1·54	4·18	4·30	3·96	6·85	5·50	1·90	1·42	2·11	4·62	4·84	1·28	44
4·72	·95	3·82	1·57	4·28	4·40	4·05	7·01	5·62	1·94	1·45	2·15	4·73	4·95	1·31	45
4·83	·97	3·91	1·61	4·37	4·50	4·14	7·16	5·75	1·98	1·48	2·20	4·83	5·06	1·34	46
4·93	1·00	3·99	1·64	4·47	4·60	4·23	7·32	5·87	2·02	1·52	2·25	4·94	5·17	1·37	47
5·04	1·02	4·08	1·68	4·56	4·70	4·32	7·47	6·00	2·07	1·55	2·29	5·04	5·28	1·40	48
5·14	1·04	4·16	1·71	4·66	4·79	4·41	7·63	6·12	2·11	1·59	2·34	5·15	5·39	1·43	49
5·25	1·07	4·25	1·75	4·75	4·89	4·50	7·78	6·25	2·16	1·62	2·39	5·25	5·50	1·45	50
5·35	1·09	4·33	1·78	4·85	4·99	4·59	7·94	6·37	2·20	1·65	2·44	5·36	5·61	1·48	51
5·46	1·11	4·42	1·82	4·94	5·09	4·68	8·10	6·50	2·24	1·68	2·49	5·46	5·72	1·51	52
5·56	1·13	4·50	1·85	5·05	5·19	4·77	8·26	6·62	2·28	1·71	2·54	5·57	5·83	1·54	53
5·67	1·15	4·59	1·89	5·13	5·29	4·86	8·42	6·75	2·32	1·73	2·59	5·67	5·94	1·57	54
5·77	1·17	4·69	1·92	5·23	5·39	4·95	8·58	6·87	2·36	1·76	2·64	5·78	6·05	1·60	55
5·88	1·19	4·77	1·96	5·32	5·49	5·04	8·73	7·00	2·40	1·79	2·69	5·88	6·16	1·62	56
5·98	1·21	4·85	1·99	5·42	5·59	5·13	8·89	7·12	2·45	1·83	2·74	5·99	6·27	1·65	57
6·09	1·23	4·94	2·03	5·51	5·68	5·22	9·05	7·25	2·49	1·86	2·78	6·09	6·38	1·68	58
6·19	1·25	5·02	2·06	5·61	5·78	5·31	0·20	7·37	2·53	1·89	2·83	6·20	6·49	1·70	59
6·30	1·27	5·11	2·10	5·70	5·88	5·40	9·35	7·50	2·58	1·93	2·88	6·31	6·60	1·72	60
6·40	1·29	5·19	2·13	5·80	5·98	5·49	9·51	7·62	2·62	1·96	2·93	6·41	6·71	1·75	61
6·51	1·31	5·28	2·17	5·89	6·07	5·58	9·66	7·75	2·66	1·99	2·98	6·52	6·82	1·78	62
6·61	1·33	5·36	2·20	5·99	6·17	5·67	9·82	7·87	2·71	2·02	3·03	6·62	6·93	1·81	63
6·72	1·35	5·45	2·24	6·08	6·27	5·76	9·98	8·00	2·75	2·06	3·08	6·73	7 04	1·84	64
6·82	1·37	5·53	2·27	6·18	6·37	5·85	10·14	8·12	2·79	2·09	3·12	6·83	7·15	1·87	65
6·93	1·39	5·62	2·31	6·27	6·46	5·94	10·29	8·25	2·84	2·12	3·17	6·94	7·26	1·89	66
7·03	1·41	5·70	2·34	6·37	6·56	6·03	10·44	8·37	2·88	2·15	3·22	7·04	7·37	1·91	67
7·14	1·43	5·79	2·38	6·46	6·66	6·12	10·59	8·50	2·92	2·19	3·27	7·15	7·48	1·94	68
7·24	1·45	5·87	2·41	6·56	6·76	6·21	10·75	8·62	2·97	2·22	3·32	7·25	7·59	1·97	69
7·35	1·47	5·96	2·44	6·65	6·85	6·30	10·90	8·75	3·01	2·25	3·37	7·36	7·70	1·99	70
7·45	1·49	6·04	2·48	6·75	6·95	6·39	11·06	8·87	3·05	2·28	3·41	7·46	7·81	2·01	71
7·56	1·51	6·13	2·51	6·84	7·05	6·48	11·22	9·00	3·09	2·31	3·46	7·57	7·92	2·03	72
7·66	1·53	6·21	2·55	6·94	7·15	6·57	11·37	9·12	3·13	2·34	3·50	7·67	8·03	2·05	73
7·77	1·55	6·30	2·58	7·03	7·24	6·66	11·53	9·25	3·18	2·38	3·55	7·78	8·14	2·07	74
7·87	1·57	6·38	2·62	7·13	7·34	6·75	11·68	9·37	3·23	2·41	3·60	7·88	8·25	2·10	75
7·98	1·67	6·46	2·66	7·22	7·45	6·84	11·93	9·50	3·27	2·43	3·64	7·98	8·36	2·20	76
8·08	1·69	6·55	2·69	7·32	7·55	6·93	12·09	9·62	3·31	2·47	3·69	8·08	8·47	2·23	77
8·19	1·70	6·63	2·73	7·41	7·65	7·02	12·25	9·75	3·35	2·50	3·74	8·19	8·58	2·26	78
8·29	1·72	6·72	2·76	7·51	7·75	7·11	12·41	9·87	3·40	2·53	3·79	8·29	8·69	2·29	79
8·40	1·73	6.80	2·80	7·60	7·85	7·20	12·57	10·00	3·44	2·56	3·84	8·40	8·80	2·32	80
8·50	1·75	6·89	2·83	7·70	7·94	7·29	12·73	10·12	3·49	2·60	3·88	8·50	8·91	2·35	81
8·61	1·76	6·97	2·87	7·79	8·04	7·38	12·89	10·25	3·53	2·63	3·93	8·61	9·02	2·38	82
8·71	1·78	7·06	2·90	7·89	8·14	7·47	13·04	10·37	3·57	2·66	3·98	8·71	9·13	2·40	83
8·82	1·79	7·14	2·94	7·98	8·24	7·56	13·20	10·50	3·61	2·69	4·03	8·82	9·24	2·43	84
8·92	1·81	7·23	2·97	8·08	8·33	7·65	13·36	10·62	3·65	2·73	4·08	8·92	9·35	2·46	85
9·03	1·82	7·31	3·01	8·17	8·43	7·74	13·40	10·75	3·69	2·76	4·13	9·03	9·46	2·49	86
9·13	1·84	7·40	3·04	8·27	8·53	7·83	13·56	10·87	3·74	2·79	4·17	9·13	9·57	2·52	87
9·24	1·85	7·48	3·08	8·36	8·63	7·92	13·72	11·00	3·78	2·83	4·22	9·24	9·68	2·55	88
9·34	1·87	7·57	3·11	8·46	8·72	8·01	13·88	11·12	3·82	2·86	4·27	9·34	9·79	2·58	89
9·45	1·89	7·66	3·15	8·55	8·82	8·10	14·04	11·25	3·86	2·89	4·32	9·45	9·90	2·60	90
9·55	1·90	7·74	3·18	8·65	8·92	8·19	14·20	11·37	3·91	2·92	4·36	9·55	10·01	2·63	91
9·66	1·92	7·83	3·22	8·74	9·01	8·28	14·36	11·50	3·95	2·95	4·41	9·66	10·12	2·66	92
9·76	1·93	7·91	3·25	8·84	9·11	8·37	14·51	11·62	3·99	2·99	4·46	9·76	10·23	2·69	93
9·87	1·95	8·00	3·29	8·93	9·21	8·46	14·67	11·75	4·03	3·02	4·51	9·87	10·34	2·72	94
9·97	1·97	8·08	3·32	9·03	9·31	8·55	14·83	11·87	4·07	3·05	4·56	9·97	10·45	2·75	95
10·08	2·00	8·17	3·36	9·12	9·41	8·64	14·99	12·00	4·11	3·08	4·61	10·08	10·56	2·78	96
10·18	2·02	8·25	3·39	9·22	9·50	8·73	15·14	12·12	4·15	3·12	4·65	10·18	10·67	2·81	97
10·29	2·05	8·34	3·43	9·31	9·60	8·82	15·30	12·25	4·19	3·15	4·70	10·29	10·78	2·84	98
10·39	2·08	8·42	3·46	9·41	9·70	8·91	15·46	12·37	4·24	3·18	4·75	10·39	10·89	2·87	99
10·50	2·11	8·51	3·50	9·50	9·80	9·00	15·61	12·50	4·28	3·22	4·85	10·50	11·00	2·90	100

Diam. of Cylinder in Inches.	Breadth of small Eye of Crank.	Length of Ditto.	Thickness of Web of Crank at Pin Centre.	Breadth of Ditto.	Lengths of Connecting Rod in Inches.	Lengths of Ditto in Feet.	Ratio between Diameters of Ditto at Middle and End.	Lengths of Connecting Rod in Inches.	Lengths of Ditto in Feet.	Ratio between Diameters of Ditto at Middle and End.	Lengths of Side Rod in Inches.	Lengths of Ditto in Feet.	Ratio between Diameters of Ditto at Middle and End.	Lengths of Side Rod in Inches.	Lengths of Ditto in Feet.	Ratio between Diameters of Ditto at Middle and End.	Diam. of Cylinder in Inches.
20	1·26	3.75	2·20	3·20	48	4	1·168	130	$10\frac{5}{6}$	1·454	36	3	1·126	118	$9\frac{5}{6}$	1·413	20
21	1·33	3·93	2·31	3·36	49	$4\frac{1}{12}$	1·171	131	$10\frac{11}{12}$	1·459	37	$3\frac{1}{12}$	1·129	119	$9\frac{11}{12}$	1·416	21
22	1·40	4·12	2·42	3·52	50	$4\frac{1}{6}$	1·175	132	11	1·462	38	$3\frac{1}{6}$	1·133	120	10	1·420	22
23	1·46	4·31	2·53	3·68	51	$4\frac{1}{4}$	1·178	133	$11\frac{1}{12}$	1·465	39	$3\frac{1}{4}$	1·136	121	$10\frac{1}{12}$	1·423	23
24	1·52	4·50	2·64	3·84	52	$4\frac{1}{3}$	1·182	134	$11\frac{1}{6}$	1·468	40	$3\frac{1}{3}$	1·140	122	$10\frac{1}{6}$	1·427	24
25	1·58	4·68	2·75	4·00	53	$4\frac{5}{12}$	1·185	135	$11\frac{1}{4}$	1·472	41	$3\frac{5}{12}$	1·143	123	$10\frac{1}{4}$	1·430	25
26	1·65	4·87	2·86	4·16	54	$4\frac{1}{2}$	1·189	136	$11\frac{1}{3}$	1·475	42	$3\frac{1}{2}$	1·147	124	$10\frac{1}{3}$	1·434	26
27	1·71	5·06	2·97	4·32	55	$4\frac{7}{12}$	1·192	137	$11\frac{5}{12}$	1·478	43	$3\frac{7}{12}$	1·150	125	$10\frac{5}{12}$	1·437	27
28	1·77	5·25	3·08	4·48	56	$4\frac{2}{3}$	1·196	138	$11\frac{1}{2}$	1·482	44	$3\frac{2}{3}$	1·154	126	$10\frac{1}{2}$	1·441	28
29	1·83	5·43	3·19	4·64	57	$4\frac{3}{4}$	1·199	139	$11\frac{7}{12}$	1·485	45	$3\frac{3}{4}$	1·157	127	$10\frac{7}{12}$	1·444	29
30	1·90	5·62	3·30	4·80	58	$4\frac{5}{6}$	1·203	140	$11\frac{2}{3}$	1·490	46	$3\frac{5}{6}$	1·160	128	$10\frac{2}{3}$	1·448	30
31	1·96	5·81	3·41	4·96	59	$4\frac{11}{12}$	1·206	141	$11\frac{3}{4}$	1·493	47	$3\frac{11}{12}$	1·164	129	$10\frac{3}{4}$	1·451	31
32	2·02	5·99	3·52	5·12	60	5	1·210	142	$11\frac{5}{6}$	1·497	48	4	1·168	130	$10\frac{5}{6}$	1·455	32
33	2·08	6·18	3·63	5·28	61	$5\frac{1}{12}$	1·213	143	$11\frac{11}{12}$	1·500	49	$4\frac{1}{12}$	1·171	131	$10\frac{11}{12}$	1·458	33
34	2·14	6·37	3·74	5·44	62	$5\frac{1}{6}$	1·217	144	12	1·504	50	$4\frac{1}{6}$	1·175	132	11	1·462	34
35	2·21	6·56	3·85	5·60	63	$5\frac{1}{4}$	1·220	145	$12\frac{1}{12}$	1·507	51	$4\frac{1}{4}$	1·178	133	$11\frac{1}{12}$	1·465	35
36	2·27	6·74	3·96	5·76	64	$5\frac{1}{3}$	1·224	146	$12\frac{1}{6}$	1·511	52	$4\frac{1}{3}$	1·182	134	$11\frac{1}{6}$	1·469	36
37	2·33	6·93	4·07	5·92	65	$5\frac{5}{12}$	1·227	147	$12\frac{1}{4}$	1·514	53	$4\frac{5}{12}$	1·185	135	$11\frac{1}{4}$	1·472	37
38	2·39	7·12	4·18	6·08	66	$5\frac{1}{2}$	1·231	148	$12\frac{1}{3}$	1·517	54	$4\frac{1}{2}$	1·189	136	$11\frac{1}{3}$	1·476	38
39	2·45	7·31	4·29	6·24	67	$5\frac{7}{12}$	1·234	149	$12\frac{5}{12}$	1·521	55	$4\frac{7}{12}$	1·192	137	$11\frac{5}{12}$	1·479	39
40	2·52	7·50	4·40	6·40	68	$5\frac{2}{3}$	1·237	150	$12\frac{1}{2}$	1·525	56	$4\frac{2}{3}$	1·196	138	$11\frac{1}{2}$	1·483	40
41	2·58	7·68	4·51	6·56	69	$5\frac{3}{4}$	1·241	151	$12\frac{7}{12}$	1·528	57	$4\frac{3}{4}$	1·199	139	$11\frac{7}{12}$	1·486	41
42	2·64	7·87	4·62	6·72	70	$5\frac{5}{6}$	1·245	152	$12\frac{2}{3}$	1·532	58	$4\frac{5}{6}$	1·203	140	$11\frac{2}{3}$	1·490	42
43	2·71	8·05	4·73	6·88	71	$5\frac{11}{12}$	1·248	153	$12\frac{3}{4}$	1·535	59	$4\frac{11}{12}$	1·206	141	$11\frac{3}{4}$	1·493	43
44	2·78	8·24	4·84	7·04	72	6	1·252	154	$12\frac{5}{6}$	1·539	60	5	1·210	142	$11\frac{5}{6}$	1·497	44
45	2·84	8·42	4·95	7·20	73	$6\frac{1}{12}$	1·255	155	$12\frac{11}{12}$	1·542	61	$5\frac{1}{12}$	1·213	143	$11\frac{11}{12}$	1·500	45
46	2·91	8·61	5·06	7·36	74	$6\frac{1}{6}$	1·259	156	13	1·546	62	$5\frac{1}{6}$	1·217	144	12	1·504	46
47	2·97	8·79	5·17	7·52	75	$6\frac{1}{4}$	1·262	157	$13\frac{1}{12}$	1·549	63	$5\frac{1}{4}$	1·221	145	$12\frac{1}{12}$	1·507	47
48	3·03	8·98	5·28	7·68	76	$6\frac{1}{3}$	1·266	158	$13\frac{1}{6}$	1·553	64	$5\frac{1}{3}$	1·224	146	$12\frac{1}{6}$	1·511	48
49	3·10	9·16	5·39	7·84	77	$6\frac{5}{12}$	1·269	159	$13\frac{1}{4}$	1·557	65	$5\frac{5}{12}$	1·227	147	$12\frac{1}{4}$	1·514	49
50	3·16	9·35	5·50	8·00	78	$6\frac{1}{2}$	1·273	160	$13\frac{1}{3}$	1·560	66	$5\frac{1}{2}$	1·231	148	$12\frac{1}{3}$	1·518	50
51	3·22	9·53	5·61	8·16	79	$6\frac{7}{12}$	1·276	161	$13\frac{5}{12}$	1·564	67	$5\frac{7}{12}$	1·234	149	$12\frac{5}{12}$	1·521	51
52	3·28	9·72	5·72	8·32	80	$6\frac{2}{3}$	1·280	162	$13\frac{1}{2}$	1·567	68	$5\frac{2}{3}$	1·236	150	$12\frac{1}{2}$	1·525	52
53	3·34	9·91	5·83	8·48	81	$6\frac{3}{4}$	1·283	163	$13\frac{7}{12}$	1·571	69	$5\frac{3}{4}$	1·240	151	$12\frac{7}{12}$	1·528	53
54	3·41	10·09	5·94	8·64	82	$6\frac{5}{6}$	1·287	164	$13\frac{2}{3}$	1·574	70	$5\frac{5}{6}$	1·245	152	$12\frac{2}{3}$	1·532	54
55	3·47	10·28	6·05	8·80	83	$6\frac{11}{12}$	1·291	165	$13\frac{3}{4}$	1·578	71	$5\frac{11}{12}$	1·248	153	$12\frac{3}{4}$	1·535	55
56	3·53	10·46	6·16	8·96	84	7	1·294	166	$13\frac{5}{6}$	1·581	72	6	1·252	154	$12\frac{5}{6}$	1·539	56
57	3·59	10·65	6·27	9·12	85	$7\frac{1}{12}$	1·297	167	$13\frac{11}{12}$	1·584	73	$6\frac{1}{12}$	1·255	155	$12\frac{11}{12}$	1·542	57
58	3·66	10·84	6·38	9·28	86	$7\frac{1}{6}$	1·301	168	14	1·588	74	$6\frac{1}{6}$	1·259	156	13	1·546	58
59	3·72	11·02	6·49	9·44	87	$7\frac{1}{4}$	1·304	169	$14\frac{1}{12}$	1·591	75	$6\frac{1}{4}$	1·262	157	$13\frac{1}{12}$	1·549	59
60	3·78	11·20	6·60	9.60	88	$7\frac{1}{3}$	1·308	170	$14\frac{1}{6}$	1·595	76	$6\frac{1}{3}$	1·266	158	$13\frac{1}{6}$	1·553	60
61	3·84	11·39	6·71	9·76	89	$7\frac{5}{12}$	1·311	171	$14\frac{1}{4}$	1·598	77	$6\frac{5}{12}$	1·269	159	$13\frac{1}{4}$	1·556	61
62	3·91	11·57	6·82	9·92	90	$7\frac{1}{2}$	1·315	172	$14\frac{1}{3}$	1·602	78	$6\frac{1}{2}$	1·273	160	$13\frac{1}{3}$	1·560	62
63	3·98	11·76	6·93	10·08	91	$7\frac{7}{12}$	1·318	173	$14\frac{5}{12}$	1·605	79	$6\frac{7}{12}$	1·276	161	$13\frac{5}{12}$	1·563	63
64	4·04	11·94	7·04	10·24	92	$7\frac{2}{3}$	1·322	174	$14\frac{1}{2}$	1·609	80	$6\frac{2}{3}$	1·280	162	$13\frac{1}{2}$	1·567	64
65	4·11	12·13	7·15	10·40	93	$7\frac{3}{4}$	1·325	175	$14\frac{7}{12}$	1·612	81	$6\frac{3}{4}$	1·283	163	$13\frac{7}{12}$	1·570	65
66	4·17	12·31	7·26	10·56	94	$7\frac{5}{6}$	1·329	176	$14\frac{2}{3}$	1·616	82	$6\frac{5}{6}$	1·287	164	$13\frac{2}{3}$	1·574	66
67	4·23	12·50	7·37	10·72	95	$7\frac{11}{12}$	1·332	177	$14\frac{3}{4}$	1·619	83	$6\frac{11}{12}$	1·290	165	$13\frac{3}{4}$	1·577	67
68	4·29	12·68	7·48	10·88	96	8	1·336	178	$14\frac{5}{6}$	1·623	84	7	1·294	166	$13\frac{5}{6}$	1·581	68
69	4·35	12·87	7·59	11·04	97	$8\frac{1}{12}$	1·339	179	$14\frac{11}{12}$	1·626	85	$7\frac{1}{12}$	1·297	167	$13\frac{11}{12}$	1·584	69
70	4·42	13·06	7·70	11·20	98	$8\frac{1}{6}$	1·343	180	15	1·630	86	$7\frac{1}{6}$	1·301	168	14	1·588	70
71	4·48	13·25	7·81	11·36	99	$8\frac{1}{4}$	1·346	181	$15\frac{1}{12}$	1·633	87	$7\frac{1}{4}$	1·304	169	$14\frac{1}{12}$	1·591	71
72	4·54	13·44	7·92	11·52	100	$8\frac{1}{3}$	1·350	182	$15\frac{1}{6}$	1·637	88	$7\frac{1}{3}$	1·308	170	$14\frac{1}{6}$	1·595	72
73	4·60	13·63	8·03	11·68	101	$8\frac{5}{12}$	1·353	183	$15\frac{1}{4}$	1·640	89	$7\frac{5}{12}$	1·311	171	$14\frac{1}{4}$	1·598	73
74	4·67	13·81	8·14	11·84	102	$8\frac{1}{2}$	1·357	184	$15\frac{1}{3}$	1·644	90	$7\frac{1}{2}$	1·315	172	$14\frac{1}{3}$	1·602	74
75	4·73	14·00	8·25	12·00	103	$8\frac{7}{12}$	1·360	185	$15\frac{5}{12}$	1·647	91	$7\frac{7}{12}$	1·318	173	$14\frac{5}{12}$	1·605	75
76	4·79	14·19	8·36	12·16	104	$8\frac{2}{3}$	1·364	186	$15\frac{1}{2}$	1·651	92	$7\frac{2}{3}$	1·321	174	$14\frac{1}{2}$	1·609	76
77	4·85	14·38	8·47	12·32	105	$8\frac{3}{4}$	1·367	187	$15\frac{7}{12}$	1·654	93	$7\frac{3}{4}$	1·325	175	$14\frac{7}{12}$	1·612	77
78	4·91	14·56	8·58	12·48	106	$8\frac{5}{6}$	1·371	188	$15\frac{2}{3}$	1·658	94	$7\frac{5}{6}$	1·328	176	$14\frac{2}{3}$	1·616	78
79	4·97	14·75	8·69	12·64	107	$8\frac{11}{12}$	1·374	189	$15\frac{3}{4}$	1·661	95	$7\frac{11}{12}$	1·332	177	$14\frac{3}{4}$	1·619	79
80	5·03	14·94	8·80	12·80	108	9	1·378	190	$15\frac{5}{6}$	1·665	96	8	1·336	178	$14\frac{5}{6}$	1·623	80
81	5·10	15·13	8·91	12·96	109	$9\frac{1}{12}$	1·381	191	$15\frac{11}{12}$	1·668	97	$8\frac{1}{12}$	1·339	179	$14\frac{11}{12}$	1·626	81
82	5·16	15·32	9·02	13·12	110	$9\frac{1}{6}$	1·385	192	16	1·672	98	$8\frac{1}{6}$	1·343	180	15	1·630	82
83	5·22	15·50	9·13	13·28	111	$9\frac{1}{4}$	1·388	193	$16\frac{1}{12}$	1·675	99	$8\frac{1}{4}$	1·346	181	$15\frac{1}{12}$	1·633	83
84	5·29	15·69	9·24	13·44	112	$9\frac{1}{3}$	1·392	194	$16\frac{1}{6}$	1·679	100	$8\frac{1}{3}$	1·350	182	$15\frac{1}{6}$	1·637	84
85	5·35	15·88	9·35	13·60	113	$9\frac{5}{12}$	1·395	195	$16\frac{1}{4}$	1·682	101	$8\frac{5}{12}$	1·353	183	$15\frac{1}{4}$	1·641	85
86	5·41	16·07	9·46	13·76	114	$9\frac{1}{2}$	1·399	196	$16\frac{1}{3}$	1·686	102	$8\frac{1}{2}$	1·357	184	$15\frac{1}{3}$	1·645	86
87	5·48	16·26	9·57	13·92	115	$9\frac{7}{12}$	1·402	197	$16\frac{5}{12}$	1·689	103	$8\frac{7}{12}$	1·360	185	$15\frac{5}{12}$	1·648	87
88	5·54	16·44	9·68	14·08	116	$9\frac{2}{3}$	1·406	198	$16\frac{1}{2}$	1·693	104	$8\frac{2}{3}$	1·364	186	$15\frac{1}{2}$	1·652	88
89	5·61	16·63	9·79	14·24	117	$9\frac{3}{4}$	1·409	199	$16\frac{7}{12}$	1·696	105	$8\frac{3}{4}$	1·367	187	$15\frac{7}{12}$	1·655	89
90	5·67	16·82	9·90	14·40	118	$9\frac{5}{6}$	1·413	200	$16\frac{2}{3}$	1·700	106	$8\frac{5}{6}$	1·371	188	$15\frac{2}{3}$	1·659	90
91	5·73	17·01	10·01	14·56	119	$9\frac{11}{12}$	1·416	201	$16\frac{3}{4}$	1·703	107	$8\frac{11}{12}$	1·374	189	$15\frac{3}{4}$	1·662	91
92	5·80	17·20	10·12	14·72	120	10	1·420	202	$16\frac{5}{6}$	1·707	108	9	1·378	190	$15\frac{5}{6}$	1·666	92
93	5·86	17·39	10·23	14·88	121	$10\frac{1}{12}$	1·423	203	$16\frac{11}{12}$	1·710	109	$9\frac{1}{12}$	1·381	191	$15\frac{11}{12}$	1·669	93
94	5·92	17·58	10·34	15·04	122	$10\frac{1}{6}$	1·427	204	17	1·714	110	$9\frac{1}{6}$	1·385	192	16	1·673	94
95	5·99	17·76	10·45	15·20	123	$10\frac{1}{4}$	1·430	205	$17\frac{1}{12}$	1·717	111	$9\frac{1}{4}$	1·388	193	$16\frac{1}{12}$	1·676	95
96	6·05	17·95	10·56	15·36	124	$10\frac{1}{3}$	1·434	206	$17\frac{1}{6}$	1·721	112	$9\frac{1}{3}$	1·392	194	$16\frac{1}{6}$	1·680	96
97	6·11	18·14	10·67	15·52	125	$10\frac{5}{12}$	1·437	207	$17\frac{1}{4}$	1·724	113	$9\frac{5}{12}$	1·395	195	$16\frac{1}{4}$	1·683	97
98	6·17	18·37	10·78	15·68	126	$10\frac{1}{2}$	1·441	208	$17\frac{1}{3}$	1·728	114	$9\frac{1}{2}$	1·399	196	$16\frac{1}{3}$	1·687	98
99	6·24	18·56	10·89	15·84	127	$10\frac{7}{12}$	1·444	209	$17\frac{5}{12}$	1·731	115	$9\frac{7}{12}$	1·402	197	$16\frac{5}{12}$	1·690	99
100	6·30	18·75	11·00	16·00	128	$10\frac{2}{3}$	1·448	210	$17\frac{1}{2}$	1·735	116	$9\frac{2}{3}$	1·406	198	$16\frac{1}{2}$	1·794	100
					129	$10\frac{3}{4}$	1·451	211	$17\frac{7}{12}$	1·738	117	$9\frac{3}{4}$	1·409	199	$16\frac{7}{12}$	1·797	

Diameter of Cylinder, in Inches.	Dimensions of several Parts of Cylinder Side Rods.							Dimensions of several Parts of Side Lever, and Side Lever Centres.								Diameter of Cylinder, in Inches.
	Diameter of Cylinder Side Rods at Ends, in Inches.	Breadth of Butt, in Inches.	Thickness of Butt, in Inches.	Mean Thickness of Strap at Cutter, in Inches.	Mean Thickness of Strap below Cutter, in Inches.	Depth of Gibs and Cutter, in Inches.	Thickness of Gibs and Cutter, in Inches.	Diameter of Main Centre Journal, in Inches.	Length of Main Centre Journal, in Inches.	Depth of Eye round End Studs of Lever, in Inches.	Thickness of Eye round End Studs, in Inches.	Diameter of End Studs, in Inches.	Length of End Studs, in Inches.	Diameter of Air Pump Studs, in Inches.	Length of Air Pump Studs, in Inches.	
23	1·47	1·76	1·40	·74	·54	1·84	·37	4·20	6·32	1·71	1·21	1·61	1·74	1.05	1·13	23
24	1·53	1·84	1·46	·77	·56	1·92	·39	4·39	6·60	1·79	1·25	1·68	1·82	1·09	1·18	24
25	1·59	1·92	1·52	·80	·59	2·00	·40	4·57	6·87	1·86	1·30	1·75	1·89	1·14	1·23	25
26	1·66	2·00	1·58	·84	·61	2·08	·42	4·75	7·15	1·93	1·36	1·82	1·96	1·18	1·28	26
27	1·73	2·08	1·64	·87	·63	2·16	·43	4·94	7·42	2·01	1·41	1·89	2·04	1·23	1·33	27
28	1·79	2·15	1·70	·90	·65	2·24	·45	5·12	7·70	2·08	1·46	1·96	2·12	1·27	1·37	28
29	1·85	2·22	1·76	·93	·67	2·32	·46	5·30	7·97	2·15	1·51	2·03	2·20	1·32	1·42	29
30	1·91	2·30	1·83	·96	·69	2·40	·48	5·48	8·25	2·23	1·56	2·10	2·27	1·36	1·47	30
31	1·98	2·38	1·90	1·00	·71	2·48	·49	5·56	8·52	2·30	1·62	2·17	2·35	1·41	1·52	31
32	2·04	2·46	1·96	1·03	·73	2·56	·51	5·74	8·80	2·38	1·67	2·24	2·43	1·45	1·57	32
33	2·10	2·54	2·02	1·06	·75	2·64	·53	5·92	9·07	2·45	1·72	2·31	2·51	1·50	1·62	33
34	2·18	2·62	2·07	1·09	·78	2·72	·54	6·10	9·35	2·52	1·77	2·38	2·58	1·54	1·67	34
35	2·24	2·70	2·13	1·12	·80	2·80	·56	6·28	9·62	2·60	1·82	2·45	2·66	1·59	1·72	35
36	2·30	2·78	2·19	1·15	·82	2·88	·57	6·46	9·90	2·67	1·88	2·52	2·73	1·64	1·77	36
37	2·37	2·85	2·25	1·19	·85	2·96	·59	6·65	10·17	2·75	1·93	2·59	2·81	1·68	1·82	37
38	2·43	2·93	2·31	1·22	·87	3·04	·60	6·83	10·45	2·82	1·98	2·66	2·88	1·73	1·87	38
39	2·49	3·01	2·37	1·25	·90	3·12	·62	7·02	10·72	2·89	2·03	2·73	2·96	1·78	1·92	39
40	2·55	3·08	2·43	1·29	·92	3·20	·64	7·20	11·00	2·97	2·08	2·80	3·03	1·82	1·97	40
41	2·62	3·16	2·49	1·32	·95	3·28	·65	7·39	11·27	3·04	2·13	2·87	3·11	1·87	2·01	41
42	2·68	3·24	2·56	1·35	·97	3·36	·67	7·57	11·55	3·12	2·18	2·94	3·18	1·91	2·06	42
43	2·75	3·31	2·62	1·38	·99	3·44	·68	7·76	11·82	3·19	2·23	3·01	3·26	1·96	2·11	43
44	2·81	3·39	2·68	1·42	1·01	3·52	·70	7·94	12·10	3·27	2·28	3·08	3·33	2·00	2·16	44
45	2·88	3·47	2·75	1·45	1·03	3·60	·71	8·12	12·37	3·34	2·34	3·15	3·41	2·05	2·21	45
46	2·95	3·54	2·81	1·48	1·06	3·68	·73	8·31	12·65	3·42	2.39	3·22	3·49	2·09	2·26	46
47	3·01	3·62	2·87	1·52	1·08	3·76	·75	8·50	12·92	3·49	2·44	3·29	3·56	2·14	2·31	47
48	3·08	3·70	2·93	1·55	1·10	3·84	·76	8·68	13·20	3·56	2·49	3·36	3·64	2·18	2·36	48
49	3·14	3·77	2·99	1·59	1·13	3·92	·78	8·87	13·47	3·64	2·54	3·43	3·71	2·23	2·50	49
50	3·21	3·85	3·06	1·62	1·15	4·00	·80	9·05	13·75	3·71	2·60	3·50	3·78	2·27	2·76	50
51	3·27	3·93	3·12	1·65	1·17	4·08	·82	9·24	14·02	3·78	2·65	3·57	3·86	2·32	2·78	51
52	3·33	4·01	3·18	1·68	1·19	4·16	·83	9·43	14·30	3·86	2·70	3·64	3·94	2·36	2·80	52
53	3·40	4·08	3·24	1·71	1·22	4·24	·85	9·62	14·57	3·93	2·75	3·71	4·02	2·41	2·82	53
54	3·46	4·16	3·29	1·73	1·24	4·32	·86	9·81	14·85	4·01	2·80	3·78	4·10	2·45	2·84	54
55	3·52	4·24	3·35	1·76	1·26	4·40	·88	10·00	15·12	4·09	2·86	3·85	4·18	2·50	2·86	55
56	3·59	4·32	3·41	1·79	1·29	4·48	·89	10·19	15·40	4·16	2·92	3·92	4·25	2·54	2·88	56
57	3·65	4·40	3·47	1·82	1·31	4·56	·91	10·38	15·67	4·24	2·97	3·99	4·33	2·59	2·90	57
58	3·72	4·47	3·53	1·86	1·33	4·64	·93	10·57	15·95	4·31	3·02	4·06	4·41	2·64	2·92	58
59	3·78	4·55	3·59	1·89	1·35	4·72	·94	10·76	16·22	4·39	3·07	4·13	4·48	2·68	2·94	59
60	3·85	4·63	3·66	1·92	1·38	4·80	·96	10·95	16·50	4·46	3·12	4·20	4·56	2·73	2·96	60
61	3·91	4·70	3·72	1·95	1·40	4·88	·97	11·14	16·77	4·53	3·17	4·27	4·63	2·77	3·01	61
62	3·97	4·78	3·78	1·99	1·42	4·96	·99	11·33	17·05	4·61	3·22	4·34	4·71	2·82	3·06	62
63	4·03	4·86	3·84	2·03	1·45	5·04	1·01	11·52	17·32	4·68	3·28	4·41	4·78	2·86	3·11	63
64	4·10	4·93	3·90	2·06	1·47	5·12	1·03	11·71	17·60	4·75	3·33	4·48	4·86	2·91	3·16	64
65	4·16	5·00	3·96	2·09	1·49	5·20	1·04	11·90	17·87	4·83	3·38	4·55	4·93	2·95	3·21	65
66	4·22	5·08	4·03	2·12	1·52	5·28	1·06	12·09	18·15	4·90	3·43	4·62	5·01	3·00	3·26	66
67	4·29	5·15	4·09	2·16	1·57	5·36	1·07	12·28	18·42	4·98	3·48	4·69	5·09	3·04	3·31	67
68	4·35	5·23	4·15	2·19	1·60	5·44	1·09	12·47	18·70	5·05	3·54	4·76	5·16	3·09	3·36	68
69	4·41	5·31	4·22	2·23	1·62	5·52	1·11	12·66	18·97	5·13	3·59	4·83	5·24	3·13	3·41	69
70	4·48	5·38	4·28	2·26	1·65	5·60	1·13	12·85	19·25	5·20	3·64	4·90	5·32	3·18	3·46	70
71	4·54	5·46	4·34	2·29	1·67	5·68	1·14	13·03	19·52	5·28	3·70	4·97	5·39	3·23	3·51	71
72	4·60	5·53	4·40	2·32	1·69	5·76	1·15	13·21	19·80	5·35	3·75	5·04	5·47	3·27	3·56	72
73	4·67	5·61	4·46	2·36	1·71	5·84	1·17	13·40	20·07	5·43	3·80	5·11	5·54	3·32	3·61	73
74	4·73	5·68	4·52	2·39	1·73	5·92	1·18	13·58	20·35	5·50	3·85	5·18	5·62	3·36	3·66	74
75	4·79	5·76	4·58	2·43	1·75	6·00	1·20	13·76	20·62	5·57	3·90	5·25	5·69	3·40	3·71	75
76	4·94	5·85	4·64	2·45	1·77	6·08	1·22	13·94	20·90	5·65	3·96	5·32	5·78	3·45	3·76	76
77	5·00	5·93	4·70	2·48	1·79	6·16	1·23	14·13	21·17	5·72	4·01	5·39	5·86	3·49	3·81	77
78	5·07	6·01	4·76	2·51	1·81	6·24	1·25	14·31	21·45	5·80	4·06	5·46	5·93	3·54	3·86	78
79	5·13	6·08	4·82	2·54	1·83	6·32	1·26	14·49	21·72	5·87	4·11	5·53	6·01	3·59	3·91	79
80	5·20	6·15	4·88	2·57	1·85	6·40	1·28	14·67	22·00	5·94	4·16	5·60	6·09	3·64	3·96	80
81	5·26	6·23	4·94	2·61	1·87	6·48	1·30	14·85	22·27	6·01	4·22	5·67	6·16	3·68	4·01	81
82	5·33	6·31	5·00	2·64	1·89	6·56	1·31	15·03	22·55	6·09	4·27	5·74	6·24	3·73	4·06	82
83	5·40	6·38	5·07	2·67	1·91	6·64	1·33	15·21	22·82	6·16	4·32	5·81	6·31	3·77	4·11	83
84	5·46	6·46	5·13	2·70	1·93	6·72	1·34	15·40	23·10	6·23	4·37	5·88	6·39	3·82	4·16	84
85	5·53	6·54	5·19	2·73	1·95	6·80	1·36	15·59	23·37	6·31	4·42	5·95	6·47	3·86	4·21	85
86	5·60	6·61	5·25	2·77	1·97	6·88	1·38	15·77	23·64	6·38	4·48	6·02	6·54	3·91	4·26	86
87	5·66	6·69	5·31	2·80	1·99	6·96	1·39	15·95	23·91	6·45	4·53	6·09	6·62	3·95	4·31	87
88	5·73	6·77	5·37	2·83	2·02	7·04	1·41	16·13	24·19	6·53	4·58	6·16	6·70	4·00	4·36	88
89	5·79	6·84	5·43	2·86	2·04	7·12	1·42	16·31	24·46	6·61	4·63	6·23	6·77	4·04	4·40	89
90	5·85	6·92	5·50	2·90	2·06	7·20	1·44	16·50	24·74	6·69	4·68	6·30	6·84	4·09	4·45	90
91	5·91	7·00	5·56	2·93	2·08	7·28	1·46	16·68	25·01	6·76	4·74	6·37	6·92	4·13	4·50	91
92	5·98	7·08	5·62	2·96	2·11	7·36	1·47	16·87	25·29	6·84	4·79	6·44	6·99	4·18	4·54	92
93	6·04	7·15	5·68	2·99	2·13	7·44	1·49	17·05	25·56	6·91	4·84	6·51	7·07	4·23	4·59	93
94	6·11	7·23	5·74	3·02	2·15	7·52	1·50	17·23	25·84	6·99	4·89	6·58	7·14	4·27	4·64	94
95	6·17	7·31	5·80	3·05	2·17	7·60	1·52	17·41	26·11	7·06	4·94	6·65	7·22	4·32	4·69	95
96	6·24	7·38	5·87	3·08	2·19	7·68	1·54	17·59	26·39	7·13	5·00	6·72	7·30	4·36	4·74	96
97	6·30	7·46	5·93	3·12	2·21	7·76	1·55	17·81	26·74	7·21	5·05	6·79	7·37	4·41	4·79	97
96	6·37	7·54	5·99	3·15	2·24	7·84	1·57	17·99	27·01	7·28	5·10	6·86	7·45	4·45	4·84	98
99	6·43	7·61	6·05	3·18	2·26	7·92	1·58	18·17	27·27	7·36	5·15	6·93	7·52	4·50	4·89	99
100	6·50	7·69	6·11	3·20	2·29	8·00	1·60	18·35	27·54	7·43	5·20	7·00	7·60	4·55	4·94	100

Diameter of Cylinder, in Inches.	Depth in Inches of Side Lever at Centre, when of Cast Iron.															Diameter of Cylinder, in Inches.
	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
20	13·34	13·88	14·37	14·84	15·27	15·69	16·08	16·45	16·81	17·15	17·48	17·81	18·11	18·41	18·69	20
21	13·77	14·33	14·84	15·32	15·76	16·20	16·60	16·98	17·35	17·70	18·05	18·38	18·69	19·00	19·29	21
22	14·20	14·77	15·30	15·79	16·25	16·70	17·11	17·51	17·89	18·25	18·61	18·95	19·27	19·59	19·89	22
23	14·63	15·22	15·76	16·27	16·74	17·20	17·62	18·03	18·43	18·80	19·17	19·52	19·85	20·18	20·49	23
24	15·06	15·67	16·22	16·74	17·23	17·70	18·13	18·55	18·97	19·35	19·73	20·09	20·43	20·77	21·09	24
25	15·48	16·11	16·68	17·22	17·72	18·20	18·65	19·09	19·51	19·90	20·29	20·66	21·01	21·36	21·69	25
26	15·88	16·53	17·12	17·67	18·18	18·67	19·14	19·59	20·02	20·42	20·82	21·20	21·56	21·92	22·25	26
27	16·28	16·94	17·55	18·11	18·64	19·14	19·63	20·09	20·53	20·94	21·35	21·74	22·11	22·48	22·81	27
28	16·68	17·36	17·98	18·55	19·09	19·61	20·11	20·58	21·03	21·46	21·87	22·27	22·65	23·03	23·37	28
29	17·08	17·78	18·41	19·00	19·54	20·08	20·59	21·07	21·53	21·97	22·39	22·80	23·19	23·58	23·93	29
30	17·48	18·19	18·84	19·44	20·01	20·55	21·07	21·56	22·03	22·48	22·91	23·33	23·73	24·13	24·49	30
31	17·86	18·59	19·25	19·87	20·45	21·00	21·53	22·04	22·52	22·98	23·41	23·84	24·25	24·66	25·03	31
32	18·24	18·98	19·66	20·29	20·89	21·45	21·98	22·51	23·01	23·47	23·91	24·35	24·77	25·18	25·56	32
33	18·62	19·38	20·06	20·71	21·32	21·90	22·43	22·97	23·48	23·95	24·41	24·86	25·28	25·70	26·09	33
34	19·00	19·77	20·46	21·13	21·75	22·34	22·88	23·43	23·95	24·43	24·90	25·36	25·79	26·22	26·62	34
35	19·38	20·16	20·88	21·55	22·18	22·78	23·33	23·89	24·42	24·91	25·39	25·86	26·30	26·74	27·15	35
36	19·74	20·54	21·27	21·95	22·60	23·21	23·77	24·34	24·88	25·38	25·87	26·35	26·79	27·24	27·66	36
37	21·10	20·92	21·66	22·35	23·01	23·64	24·21	24·79	25·34	25·85	26·34	26·83	27·28	27·74	28·17	37
38	21·46	21·29	22·04	22·75	23·42	24·06	24·65	25·24	25·79	26·31	26·81	27·31	27·77	28·24	28·67	38
39	21·82	21·66	22·42	23·15	23·83	24·48	25·08	25·68	26·24	26·77	27·28	27·78	28·26	28·74	29·17	39
40	21·18	22·03	22·82	23·55	24·24	24·90	25·52	26·12	26·69	27·23	27·75	28·27	28·75	29·23	29·67	40
41	21·53	22·39	23·20	23·94	24·64	25·31	25·94	26 55	27·13	27·68	28·21	28·74	29·22	29·71	30·16	41
42	21·87	22·75	23·58	24·33	25·04	25·72	26·36	26·98	27·53	28·13	28·67	29·20	29·69	30·19	30·65	42
43	22·22	23·11	23·96	24·71	25·44	26·13	26·78	27·41	27·97	28·57	29·12	29·66	30·16	30·67	31·13	43
44	22·56	23·47	24·34	25·10	25·84	26·53	27·20	27·83	28·40	29·01	29·57	30·12	30·62	31·14	31·61	44
45	22·91	23·83	24·68	25·48	26·23	26·93	27·61	28·25	28·87	29·45	30·02	30·58	31·09	31·61	32·09	45
46	23·25	24·19	25·04	25·85	26·62	27·33	28·02	28·67	29·29	29·88	30·46	31·03	31·55	32·07	32·56	46
47	23·58	24·55	25·40	26·22	27·00	27·72	28·42	29·08	29·71	30·31	30·90	31·48	32·01	32·53	33·03	47
48	23·91	24·90	25·76	26·59	27·38	28·11	28·82	29·49	30·13	30·74	31·34	31·92	32·46	32·99	33·50	48
49	24·25	25·24	26·12	26·96	27·76	28·50	29·22	29·90	30·55	31·17	31·78	32·36	32·91	33·45	33·97	49
50	24·58	25·57	26·48	27·33	28·14	28·89	29·62	30·31	80·97	31·59	32·21	32·80	33·36	33·91	34·43	50
51	24·90	25·90	26·82	27·69	28·51	29·27	30·01	30·70	31·37	32·00	32·63	33·23	33·79	34·35	34·88	51
52	25·22	26·23	27·16	28·04	28·87	29·65	30·39	31·09	31·77	32·41	33·05	33·65	34·22	34·79	35·33	52
53	25·53	26·56	27·50	28·39	29·23	30·02	30·77	31·48	32·17	32·82	33·46	34·07	34·65	35·23	35·78	53
54	25·85	26·89	27·84	28·74	29·59	30·39	31·15	31·87	32·57	33·23	33·87	34·49	35·08	35·67	36·23	54
55	26·16	27·22	28·18	29·09	29·95	30·76	31·53	32·26	32·96	33·63	34·28	34·91	35·51	36·10	36·65	55
56	26·48	27·55	28·54	29·45	30·32	31·14	31·92	32·66	33·37	34·04	34·70	35·34	35·95	36·54	37·10	56
57	26·80	27·88	28·90	29·81	30·69	31·52	32·31	33·05	33·77	34·45	35·12	35·77	36·38	36·98	37·55	57
58	27·12	28·21	29·26	30·17	31·05	81·89	32·69	33·44	34·17	34·86	35·54	36·20	36·81	37·42	38·00	58
59	27·43	28·54	29·61	30·52	31·41	32·26	33·07	33·83	34·57	35·27	35·96	36·63	37·24	37·86	38·44	59
60	27·75	28·87	29·90	30·87	31·77	32·63	33·45	34·22	34·97	35·68	36·37	37·04	37·67	38·30	38·88	60
61	28·06	29·19	30·23	31·21	32·12	32·99	33·82	34·60	35·36	36·08	36·77	37·46	38·02	38·72	39·31	61
62	28·37	29·51	30·56	31·55	32·47	33·35	34·19	34·98	35·75	36·47	37·17	37·87	38·44	39·14	39·74	62
63	28·68	29·83	30·89	31·89	32·82	33·71	34·56	35·36	36·13	36·86	37·57	38·27	38·85	39·56	40·13	63
64	28·98	30·15	31·21	32·22	33·17	34·07	34·92	35·73	36·51	37·25	37·96	38·67	39·26	39·98	40·56	64
65	29·28	30·46	31·54	32·56	33·51	34·42	35·28	36·10	36·89	37·63	38·36	39·07	39·73	40·40	41·01	65
66	29·58	30·77	31·87	32·90	33·86	34·77	35·64	36·47	37·27	38·02	38·76	39·47	40·14	40·82	41·43	66
67	29·88	31·08	32·19	33·23	34·20	35·12	36·00	36·84	37·65	38·41	39·15	39·87	40·54	41·23	41·85	67
68	30·18	31·39	32·51	33·56	34·54	35·47	36·36	37·21	38·03	38·79	39·54	40·27	40·95	41·64	42·27	68
69	30·48	31·70	32·83	33·89	34·88	35·82	36·72	37·58	38·40	39·17	39·93	40·67	41·36	42·05	42·69	69
70	30·77	32·01	33·15	34·22	35·22	36·17	37·08	37·94	38·77	39·55	40·32	41·07	41·76	42·46	43·10	70
71	31·06	32·31	33·46	34·54	35·55	36·51	37·43	38·30	39·12	39·92	40·70	41·46	42·15	42·86	43·51	71
72	31·35	32·61	33·77	34·86	35·88	36·85	37·78	38·66	39 46	40·29	41·08	41·85	42·54	43·26	43·92	72
73	31·64	32·91	34·08	35·18	36·21	37·19	38·13	39·01	39·80	40·66	41·46	42·23	42·93	43·66	44·32	73
74	31·93	33·21	34·39	35·50	36·54	37·53	38·47	39·36	40·14	41·03	41·83	42·61	43·32	44·05	44·72	74
75	32·21	33·51	34·70	35·82	36·87	37·86	38·81	39·71	40·48	41·40	42·20	42·99	43·71	44·44	45·12	75
76	32·50	33·81	35·01	36·14	37·20	38·20	39·16	40·06	40·86	41·77	42·58	43·37	44·10	44·84	45·52	76
77	32·78	34·11	35·32	36·46	37·53	38·54	39·50	40·41	41·24	42·14	42·95	43·75	44·49	45·23	45·92	77
78	33·06	34·40	35·62	36·77	37·85	38·87	39·84	40·76	41·62	42·50	43·32	44·13	44·87	45·62	46·32	78
79	33·34	34·69	35·92	37·08	38·17	39·20	40·18	41·11	42·00	42·86	43·69	44·51	45·25	46·01	46·71	79
80	33·62	34·98	36·22	37·39	38·49	39·53	40·52	41·46	42·37	43·22	44·06	44·88	45·64	46·40	47·10	80
81	33·90	35·27	36·52	37·70	38·81	39·86	40·86	41·81	42·72	43·58	44·43	45·25	46·02	46·79	47·49	81
82	34·18	35·56	36·82	38·01	39·13	40·19	41·20	42·15	43·07	43·94	44·79	45·62	46·40	47·17	47·88	82
83	34·46	35·85	37·12	38·32	39·45	40·52	41·53	42·49	43·42	44·29	45·15	45·99	46·78	47·55	48·27	83
84	34·74	36·14	37·42	38·63	39·76	40·85	41·86	42·83	43·77	44·65	45·51	46·36	47·15	47·93	48·66	84
85	35·01	36·42	37·72	38·93	40·07	41·16	42·19	43·17	44·11	45·01	45·87	46·72	47·52	48·31	49·04	85
86	35·29	37·71	38·02	39·24	40·38	41·48	42·52	43·51	44·46	45·36	46·23	47·09	47·89	48·69	49·43	86
87	35·56	38·00	38·31	39·54	40·69	41·80	42·85	43·85	41·81	45·71	46 59	47·46	48·26	49·07	49·81	87
88	35·83	38·28	38·60	39·84	41·00	42·12	43·18	44·18	42·15	46·06	46·95	47·82	48·63	49·45	50·19	88
89	36·10	38·56	38·89	41·14	41·32	42·44	43·51	44·51	42·49	46·41	47·31	48·18	49·09	49·82	50·57	89
90	36·37	37·84	39·18	40·45	41·63	42·76	43·83	44·84	45·83	46·75	47·66	48·54	49·36	50·19	50·95	90
91	36·64	38·12	39·47	40·75	41·94	43·08	44·16	45·17	46·17	47·10	48·01	48·90	49·73	50·56	51·33	91
92	36·91	38·40	39·76	41·05	42·25	43·39	44·48	45·50	46·51	47·45	48·36	49·26	50·09	50·93	51·71	92
93	37·18	38·68	40·05	41·35	42·56	43·70	44·80	45·83	46·85	47·79	48·71	49·62	50·45	51·30	52·08	93
94	37·45	38·95	40·34	41·64	42·86	44·01	45·12	46·16	47·18	48·13	49·06	49·97	50·81	51·67	52·46	94
95	37·71	39·22	40·62	41·93	43·16	44·32	45·44	46·49	47·51	48·47	49·40	50·32	51·17	52·03	52·82	95
96	37·98	39·50	40·91	42·23	43·46	44·63	45·76	46·82	47·84	48·81	49·75	50·67	51·53	52·40	53·19	96
97	38·24	39·78	41·19	42·52	43·76	44·94	46·08	47·15	48·17	49·15	50·10	51·02	51·89	52·76	53·56	97
98	38·50	40·05	41·47	42·81	44·06	45·25	46·40	47·47	48·50	49·49	50·44	51·37	52·25	53·12	53·93	98
99	38·76	40·32	41·75	43·10	44·36	45·56	46·71	47·79	48·83	49·82	50·78	51·72	52·60	53·48	54·30	99
100	39·02	40·59	42·03	43·39	44·66	45·87	47·02	48·11	49·16	50·15	51·12	52·07	52·95	53·84	54·66	100

Length of Side Lever in Feet.

		Dimensions of Air Pump Crosshead, in Inches.								Dimensions of the Parts of Air Pump Piston Rod, in Inches.						
Diameter of Cylinder, in Inches.	Diameter of Air Pump.	Thickness of Eye for Air Pump Rod.	Depth of Eye for Air Pump Rod.	Diameter of End Journals.	Length of End Journals.	Thickness of Web at Middle.	Depth of Web at Middle.	Thickness of Web at Journal.	Depth of Web at Journal.	Diameter of Piston Rod when Copper.	Depth of Gibs and Cutter through Crosshead.	Thickness of Gibs and Cutter through Crosshead.	Depth of Cutter through Piston.	Thickness of Cutter through Piston.	Diameter of Air Pump.	Diameter of Cylinder, in Inches.
23	13·8	·56	3·97	1·19	1·33	·99	3·69	·84	1·41	1·53	1·48	·30	1·18	·47	13·8	23
24	14·4	·59	4·14	1·24	1·39	1·04	3·85	·88	1·47	1·60	1·54	·31	1·23	·49	14·4	24
25	15·0	·61	4·31	1·29	1·45	1·08	4·01	·92	1·53	1·67	1·60	·32	1·28	·51	15·0	25
26	15·6	·64	4·48	1·34	1·51	1·13	4·17	·95	1·59	1·73	1·66	·33	1·33	·54	15·6	26
27	16·2	·66	4·66	1·39	1·56	1·17	4·33	·99	1·65	1·80	1·72	·34	1·38	·56	16·2	27
28	16·8	·69	4·83	1·45	1·62	1·22	4·49	1·02	1·71	1·87	1·78	·35	1·43	·58	16·8	28
29	17·4	·71	5·00	1·50	1·68	1·26	4·65	1·06	1·77	1·94	1·84	·37	1·48	·60	17·4	29
30	18·0	·74	5·17	1·55	1·74	1·30	4·81	1·10	1·83	2·00	1·90	·38	1·53	·62	18·0	30
31	18·6	·76	5·34	1·60	1·80	1·34	4·97	1·14	1·89	2·07	1·97	·40	1·59	·65	18·6	31
32	19·2	·79	5·51	1·65	1·85	1·38	5·13	1·17	1·95	2·14	2·03	·41	1·64	·67	19·2	32
33	19·8	·81	5·69	1·70	1·91	1·43	5·29	1·21	2·01	2·21	2·09	·42	1·69	·69	19·8	33
34	20·4	·84	5·86	1·75	1·97	1·47	5·45	1·25	2·07	2·27	2·15	·43	1·74	·71	20·4	34
35	21·0	·86	6·03	1·80	2·03	1·51	5·61	1·28	2·13	2·33	2·21	·44	1·79	·73	21·0	35
36	21·6	·89	6·26	1·85	2·08	1·55	5·78	1·32	2·19	2·40	2·27	·45	1·84	·75	21·6	36
37	22·2	·91	6·37	1·90	2·14	1·59	5·94	1·35	2·25	2·47	2·33	·46	1·89	·77	22·2	37
38	22·8	·94	6·54	1·95	2·20	1·63	6·10	1·39	2·32	2·54	2·40	·47	1·95	·79	22·8	38
39	23·4	·96	6·71	2·00	2·26	1·67	6·26	1·42	2·38	2·60	2·46	·49	1·99	·81	23·4	39
40	24·0	·99	6·88	2·06	2·32	1·72	6·43	1·46	2·44	2·67	2·52	·50	2·04	·84	24·0	40
41	24·6	1·01	7·05	2·11	2·38	1·76	6·59	1·50	2·50	2·74	2·59	·52	2·09	·86	24·6	41
42	25·2	1·04	7·22	2·16	2·44	1·81	6·75	1·53	2·56	2·81	2·65	·53	2·14	·88	25·2	42
43	25·8	1·06	7·40	2·21	2·49	1·85	6·91	1·57	2·62	2·87	2·71	·55	2·19	·90	25·8	43
44	26·4	1·09	7·57	2·26	2·55	1·89	7·07	1·61	2·68	2·93	2·77	·56	2·24	·92	26·4	44
45	27·0	1·11	7·74	2·31	2·61	1·94	7·23	1·64	2·74	3·00	2·84	·57	2·29	·94	27·0	45
46	27·6	1·14	7·91	2·36	2·66	1·98	7·39	1·68	2·80	3·07	2·90	·58	2·35	·96	27·6	46
47	28·2	1·16	8·08	2·41	2·72	2·03	7·55	1·71	2·86	3·13	2·96	·59	2·40	·98	28·2	47
48	28·8	1·19	8·25	2·46	2·78	2·07	7·71	1·75	2·92	3·20	3·02	·60	2·45	1·00	28·8	48
49	29·4	1·21	8·42	2·51	2·83	2·11	7·87	1·79	2·98	3·27	3·08	·62	2·50	1·03	29·4	49
50	30·0	1·24	8·60	2·57	2·89	2·15	8·04	1·83	3·04	3·33	3·15	·64	2·55	1·05	30·0	50
51	30·6	1·26	8·77	2·62	2·95	2·20	8·20	1·86	3·10	3·40	3·21	·65	2·61	1·07	30·6	51
52	31·2	1·29	8·95	2·67	3·01	2·24	8·36	1·90	3·16	3·47	3·28	·66	2·66	1·09	31·2	52
53	31·8	1·31	9·12	2·72	3·07	2·29	8·52	1·94	3·22	3·53	3·34	·68	2·71	1·11	31·8	53
54	32·4	1·34	9·29	2·77	3·12	2·33	8·68	1·98	3·28	3·60	3·41	·69	2·76	1·13	32·4	54
55	33·0	1·36	7·46	2·83	3·18	2·38	8·84	2·01	3·34	3·67	3·47	·71	2·81	1·15	33·0	55
56	33·6	1·39	7·63	2·88	3·23	2·42	9·00	2·05	3·40	3·74	3·54	·72	2·86	1·17	33·6	56
57	34·2	1·41	7·80	2·93	3·29	2·46	9·16	2·08	3·46	3·81	3·60	·73	2·91	1·19	34·2	57
58	34·8	1·44	7·97	2·98	3·35	2·51	9·32	2·12	3·52	3·88	3·66	·74	2·96	1·21	34·8	58
59	35·4	1.46	8·15	3·03	3·41	2·55	9·49	2·16	3·58	3·95	3·72	·75	3·02	1·23	35·4	59
60	36·0	1·49	10·33	3·09	3·47	2·59	9·65	2·20	3·65	4·01	3·78	·76	3·07	1·26	36·0	60
61	36·6	1·51	10·50	3·14	3·53	2·63	9·81	2·23	3·71	4·08	3·85	·77	3·12	1·28	36·6	61
62	37·2	1·54	10·67	3·19	3·58	2·68	9·97	2·27	3·77	4·14	3·91	·78	3·17	1·30	37·2	62
63	37·8	1·56	10·84	3·24	3·64	2·72	10·13	2·31	3·83	4·21	3·98	·80	3·22	1·32	37·8	63
64	38·4	1·58	11·01	3·29	3·70	2·76	10·29	2·35	3·89	4·27	4·04	·81	3·27	1·34	38·4	64
65	39·0	1·61	11·18	3·34	3·76	2·80	10·45	2·38	3·95	4·33	4·10	·82	3·32	1·36	39·0	65
66	39·6	1·63	11·35	3·39	3·82	2·84	10·61	2·42	4·01	4·40	4·16	·83	3·37	1·38	39·6	66
67	40·2	1·65	11·53	3·44	3·88	2·88	10·77	2·46	4·07	4·46	4·23	·84	3·42	1·40	40·2	67
68	40·8	1·68	11·70	3·49	3·94	2·92	10·93	2·49	4·13	4·53	4·29	·85	3 48	1·42	40·8	68
69	41·4	1·70	11·87	3·54	4·00	2·97	11·09	2·53	4·19	4·60	4·35	·87	3 53	1·44	41·4	69
70	42·0	1·73	12·05	3·60	4·05	3·01	11·26	2·56	4·26	4·67	4·41	·88	3·58	1·46	42·0	70
71	42·6	1·75	12·22	3·65	4·11	3·06	11·42	2·60	4·32	4·73	4·48	·90	3·63	1·49	42·6	71
72	43·2	1·78	12·38	3·70	4·17	3·10	11·58	2·63	4·38	4·80	4·54	·91	3·68	1·51	43·2	72
73	43·8	1·80	12·55	3·75	4·23	3·15	11·74	2·67	4·44	4·86	4·60	·93	3·73	1·53	43·8	73
74	44·4	1·83	12·72	3·80	4·28	3·19	11·90	2·71	4·51	4·93	4·66	·95	3·78	1·55	44·4	74
75	45·0	1·85	12·89	3·85	4·34	3·24	12·06	2·74	4·57	5·00	4·73	·96	3·83	1·57	45·0	75
76	45·6	1·87	13·06	3·90	4·40	3·28	12·22	2·78	4·63	5·07	4·79	·97	3·88	1·60	45·6	76
77	46·2	1·90	13·23	3·95	4·46	3·33	12·38	2·82	4·69	5·13	4·85	·98	3·93	1·62	46·2	77
78	46·8	1·92	13·40	4·00	4·51	3·37	12·54	2·86	4·75	5·20	4·92	1·00	3·98	1·64	46·8	78
79	47·4	1·95	13·57	4·06	4·57	3·42	12·70	2·89	4·81	5·27	4·98	1·02	4·03	1·66	47·4	79
80	48·0	1·97	13·72	4·12	4·63	3·46	12·86	2·93	4·87	5·33	5·04	1·04	4·08	1·68	48·0	80
81	48·6	2·00	13·89	4·17	4·69	3·51	13·03	2·97	4·93	5·40	5·11	1·05	4·13	1·70	48·6	81
82	49·2	2·02	14·06	4·22	4·75	3·55	13·19	3·00	4·99	5·47	5·17	1·06	4·19	1·72	49·2	82
83	49·8	2·05	14·23	4·28	4·81	3·60	13·36	3·04	5·05	5·53	5·23	1·07	4·24	1·74	49·8	83
84	50·4	2·07	14·40	4·33	4·86	3·64	13·52	3·07	5·11	5·60	5·30	1·08	4·29	1·76	50·4	84
85	51·0	2·10	14·57	4·38	4·92	3·69	13·68	3·11	5·17	5·67	5·36	1·09	4·34	1·78	51·0	85
86	51·6	2·13	14·74	4·43	4·98	3·73	13·85	3·14	5·23	5·73	5·42	1·10	4·39	1·80	51·6	86
87	52·2	2·15	14·91	4·48	5·04	3·78	14·01	3·17	5·29	5.80	5·49	1·11	4·45	1·82	52·2	87
88	52·8	2·18	15·08	4·53	5·10	3·82	14·17	3·21	5·35	5·87	5·55	1·12	4·50	1·84	52·8	88
89	53·4	2·20	15·25	4·58	5·16	3·86	14·33	3·25	5·41	5·93	5·61	1·13	4·55	1·86	53·4	89
90	54·0	2·23	15·43	4·63	5·21	3·89	14·49	3·29	5·48	6·00	5·67	1·14	4·60	1·89	54·0	90
91	54·6	2·25	15·61	4·68	5·27	3·93	14·65	3·33	5·54	6·07	5·74	1·16	4·65	1·91	54·6	91
92	55·2	2·28	15·78	4·74	5·33	3·98	14·81	3·37	5·60	6·14	5·80	1·17	4·70	1·93	55·2	92
93	55·8	2·30	15·95	4·79	5·39	4·02	14·97	3·40	5·66	6·21	5·87	1·18	4·75	1·95	55·8	93
94	56·4	2·33	16·13	4·84	5·44	4·06	15 13	3·44	5·72	6·27	5·93	1·19	4·80	1·97	56·4	94
95	57·0	2·35	16·30	4·89	5·50	4·11	15·29	3·48	5·78	6·34	5·99	1·21	4·85	1·99	57·0	95
96	57·6	2·38	16·47	4·94	5·55	4·15	15·45	3·52	5·84	6·41	6·06	1·22	4·90	2·02	57·6	96
97	58·2	2·40	16·64	5·00	5·61	4·20	15·61	3·56	5·90	6·47	6·12	1·23	4·96	2·04	58·2	97
98	58·8	2·42	16·82	5·05	5·67	4·24	15·77	3·59	5·96	6·54	6·18	1·24	5·01	2·06	58·8	98
99	59·4	2·46	16·99	5·10	5·73	4·29	15·93	3·63	6·02	6·60	6·24	1·26	5·06	2·08	59·4	99
[illegible]	60·0	2·47	17·15	5·15	5·79	4·33	16·07	3·66	6·09	6·66	6·30	1·27	5·11	2·10	60·0	100

Diameter of Cylinder, in Inches.	Dimensions of several Parts of Air Pump Machinery, in Inches.							Dimensions of Parts of Valve Gearing and Parallel Motion.									
	Diameter of Air Pump Side Rods at End.	Breadth of Butt.	Thickness of Butt.	Mean Thickness of Strap at Cutter.	Mean Thickness of Strap below Cutter.	Depth of Gibs and Cutter.	Thickness of Gibs and Cutter.	Horse Power.	Diameter of Valve Shaft at Journal, in Inches.	Diameter of Parallel Motion Shaft at Journal, in Inches.	Diameter of Valve Rod, in Inches.	Diameter of Radius Rod at smallest Part, in Inches.	Area of Eccentric Rod at smallest Part, in Square Inches.	Sectional Area of Eccentric Hoop, in Square Inches.	Diameter of Eccentric Pin, in Inches.	Breadth and Thickness of Valve Lever for Eccentric Pin at Eye, in Inches.	Breadth and Thickness of Parallel Motion Crank at Eye, in Inches.
23	·89	1.06	·84	·45	·33	1·10	·23	20	3·02	1·06	·98	1·18	2·64	1·10	1.76	3·9 × 2·0	1·6 × ·6
24	·93	1·10	·87	·46	·34	1·15	·24	25	3·08	1·15	1·00	1·20	2·81	1·10	1·79	4·0 × 2·1	1·7 × ·6
25	·97	1·14	·91	·48	·35	1·19	·25	30	3·14	1·24	1·03	1·23	2·98	1·20	1·82	4·1 × 2·1	1·7 × ·6
26	1·01	1·19	·94	·50	·37	1·24	·26	35	3·20	1·33	1·06	1·25	3·15	1·50	1·85	4·1 × 2·2	1·7 × ·6
27	1·05	1·23	·98	·52	·38	1·29	·27	40	3·26	1·39	1·09	1·27	3·32	1·80	1·88	4·2 × 2·3	1·8 × ·7
28	1·09	1·28	1·02	·54	·40	1·34	·28	45	3·32	1·48	1·12	1·30	3·49	2·10	1·91	4·2 × 2·3	1·8 × ·7
29	1·12	1·33	1·06	·56	·41	1·39	·29	50	3·38	1·57	1·16	1·32	3·66	2·40	1·94	4·3 × 2·4	1·8 × ·7
30	1·16	1·39	1·10	·58	·42	1·44	·30	55	3·44	1·66	1·20	1·35	3·83	2·70	1·97	4·4 × 2·4	1·9 × ·7
31	1·20	1·44	1·13	·60	·44	1·49	·31	60	3·50	1·75	1·25	1·38	4·00	3·00	2·00	4·5 × 2·5	1·9 × ·8
32	1·24	1·48	1·17	·62	·45	1·53	·32	65	3·56	1·84	1·30	1·40	4·17	3·25	2·01	4·5 × 2·5	1·9 × ·8
33	1·28	1·53	1·21	·64	·46	1·58	·33	70	3·62	1·93	1·35	1·43	4·34	3·50	2·02	4·6 × 2·5	2·0 × ·8
34	1·32	1·57	1·24	·66	·48	1·63	·34	75	3·68	2·02	1·40	1·45	4·51	3·75	2·03	4·6 × 2·6	2·0 × ·8
35	1·36	1·62	1·28	·67	·49	1·67	·35	80	3·74	2·11	1·45	1·47	4·68	4·00	2·04	4·7 × 2·6	2·0 × .8
36	1·40	1·66	1·31	·69	·51	1·72	·36	85	3·80	2·20	1·50	1·50	4·85	4·25	2·05	4·7 × 2·6	2·1 × ·85
37	1·44	1·71	1·35	·71	·52	1·77	·37	90	3·87	2·30	1·55	1·52	5·02	4·50	2·06	4·8 × 2·6	2·2 × ·9
38	1·48	1·75	1·38	·73	·53	1·82	·38	95	3·93	2·39	1·60	1·55	5·19	4·75	2·07	4·8 × 2·6	2·3 × ·95
39	1·51	1·80	1·42	·75	·55	1·87	·39	100	3·99	2·48	1·66	1·57	5·36	5·00	2·08	4·9 × 2·6	2·4 × 1·00
40	1·55	1·85	1·46	·77	·56	1·92	·40	105	4·05	2·58	1·71	1·60	5·53	5·25	2·09	4·9 × 2·7	2·6 × 1·05
41	1·59	1·89	1·50	·79	·57	1·96	·41	110	4·12	2·67	1·76	1·62	5·70	5·50	2·10	5·0 × 2·7	2·7 × 1·1
42	1·63	1·94	1·53	·81	·59	2·01	·42	115	4·18	2·77	1·81	1·65	5·87	5·75	2·11	5·1 × 2·7	2·8 × 1·15
43	1·66	1·98	1·57	·83	·60	2·06	·43	120	4·25	2·87	1·87	1·69	6·04	6·00	2·13	5·2 × 2·7	2·9 × 1·2
44	1·70	2·03	1·61	·85	·62	2·11	·44	125	4·31	2·96	1·92	1·71	6·21	6·25	2·14	5·2 × 2·8	3·0 × 1·25
45	1·74	2·07	1·64	·86	·63	2·16	·45	130	4·37	3·06	1·97	1·74	6·38	6·50	2·15	5·3 × 2·8	3·2 × 1·3
46	1·77	2·12	1·68	·88	·65	2·20	·46	135	4·33	3·15	2·02	1·76	6·55	6·75	2·16	5·3 × 2·9	3·3 × 1·36
47	1·81	2·16	1·71	·90	·66	2·25	·47	140	4·39	3·25	2·07	1·79	6·72	7·00	2·17	5·3 × 2·9	3·4 × 1·41
48	1·85	2·21	1·75	·92	·67	2·30	·48	145	4·45	3·34	2·12	1·81	6·89	7·25	2·18	5·4 × 2·9	3·5 × 1·46
49	1·89	2·26	1·79	·94	·69	2·35	·49	150	4·52	3·44	2·18	1·84	7·06	7·50	2·19	5·4 × 2·9	3·6 × 1·51
50	1·93	2·31	1·83	·96	·70	2·40	·50	155	4·58	3·53	2·23	1·87	7·28	7·65	2·20	5·4 × 2·9	3·7 × 1·56
51	1·97	2·37	1·87	·98	·72	2·43	·51	160	4·65	3·63	2·28	1·89	7·55	8·00	2·21	5·6 × 3	3·8 × 1·61
52	2·01	2·42	1·91	1·00	·73	2·46	·52	165	4·72	3·72	2·33	1·92	7·82	8·25	2·22	5·6 × 3	3·9 × 1·66
53	2·05	2·46	1·94	1·02	·75	2·48	·53	170	4·78	3·82	2·39	1·94	8·09	8·50	2·23	5·6 × 3	4·0 × 1·71
54	2·09	2·51	1·98	1·04	·76	2·51	·54	175	4·85	3·91	2·44	1·97	8·37	8·75	2·24	5·7 × 3	4·2 × 1·76
55	2·13	2·56	2·01	1·06	·78	2·53	·55	180	5·00	4·00	2·50	2·00	8·54	9·00	2·25	5.7 × 3	4·4 × 1·81
56	2·17	2·60	2·04	1·08	·79	2·56	·56	185	5·05	4·03	2·53	2·03	8·81	9·25	2·32	5·8 × 3	4·5 × 1·85
57	2·21	2·65	2·08	1·10	·81	2·59	·57	190	5·10	4·07	2·56	2·07	9·09	9·50	2·39	5·9 × 3	4·6 × 1·89
58	2·25	2·69	2·11	1·12	·82	2·62	·58	195	5·16	4·10	2·60	2·10	9·36	9·75	2·46	6·0 × 3·1	4·7 × 1·93
59	2·28	2·73	2·15	1·14	·84	2·65	·59	200	5·21	4·14	2·63	2·14	9·63	10·00	2·53	6·1 × 3.1	4·8 × 1·97
60	2·32	2·77	2·20	1·16	·85	2·68	·59	205	5·27	4·18	2.67	2·17	9·90	10·25	2·60	6·2 × 3·1	4·9 × 2·01
61	2·36	2·82	2·24	1·18	·87	2·74	·60	210	5·32	4·21	2·71	2·21	10·18	10·50	2·67	6·4 × 3·2	5·2 × 2·10
62	2·40	2·86	2·27	1·20	·88	2·81	·61	215	5·38	4·25	2·75	2·25	10·56	10·75	2·75	6·7 × 3·2	5·4 × 2·2
63	2·44	2·91	2·31	1·22	·89	2·88	·62	220	5·43	4·28	2·83	2·28	10·59	11·00	2·83	7·0 × 3·2	5·5 × 2·2
64	2·48	2·95	2·35	1·24	·91	2·94	·63	225	5·47	4·31	2·91	2·31	10·62	11·25	2·91	7·3 × 3·3	5·6 × 2·3
65	2·52	3·00	2·38	1·26	·92	3·01	·64	230	5·50	4·34	3·00	2·34	10·70	11·50	3·00	7·6 × 3·3	5·7 × 2·3
66	2·56	3·04	2·42	1·28	·94	3·07	·65	235	5·54	4·37	3·06	2·37	10·97	11·75	3·08	7·8 × 3·3	5·8 × 2·4
67	2·60	3·09	2·45	1·30	·95	3·14	·66	240	5·58	4·40	3·12	2·40	11·24	12·00	3·16	8·0 × 3·3	5·9 × 2·4
68	2·64	3·13	2·49	1·32	·97	3·21	·67	245	5·62	4·43	3·18	2·43	11·51	12·25	3·24	8·2 × 3·3	6·1 × 2·5
69	2·67	3·18	2·52	1·34	·98	3·28	·68	250	5·66	4·46	3·24	2·46	11·71	12·50	3·32	8·4 × 3·4	6·2 × 2·5
70	2·71	3·23	2·56	1·35	·99	3·36	·69	255	5·70	4·49	3·30	2·49	11·91	12·75	3·40	8·6 × 3·4	6·3 × 2·6
71	2·75	3·27	2·60	1·37	1·00	3·41	·70	260	5·74	4·52	3·36	2·52	12·11	13·00	3·48	8·8 × 3·4	6·4 × 2·6
72	2·79	3·32	2·63	1·39	1·02	3·46	·71	265	5·77	4·55	3·42	2·55	12·32	13·25	3·56	9·0 × 3·4	6·6 × 2·7
73	2·83	3·37	2·67	1·41	1·03	3·50	·72	270	5·80	4·58	3·47	2·58	12·53	13·50	3·64	9·2 × 3·4	6·7 × 2·7
74	2·87	3·41	2·70	1·43	1·05	3·55	·73	275	5·84	4·61	3·53	2·61	12·74	13·75	3·72	9·4 × 3·5	6·9 × 2·8
75	2·91	3·46	2·74	1·45	1·06	3·60	·74	280	5·88	4·64	3·58	2·64	12·95	14·00	3·80	9·6 × 3·5	7· × 2·8
76	2·97	3·50	2·77	1·47	1·08	3·65	·75	285	5·92	4·67	3·63	2·67	13·16	14·25	3·88	9·8 × 3·5	7·1 × 2·9
77	3·01	3·55	2·81	1·49	1·09	3·69	·76	290	5·96	4·70	3·68	2·70	13·37	14·50	3·96	10·0 × 3·5	7·2 × 2·9
78	3·04	3·60	2·84	1·51	1·11	3·74	·77	295	5·99	4·73	3·73	2·73	13·58	14·75	4·04	10·2 × 3·6	7·3 × 3·0
79	3·07	3·65	2·88	1·53	1·12	3·79	·78	300	6·03	4·76	3·77	2·76	13·79	15·00	4·12	10·4 × 3·6	7·5 × 3·0
80	3·10	3·70	2·93	1·54	1·13	3·84	·79	305	6·07	4·79	3·81	2·79	13·99	15·25	4·20	10·6 × 3·6	7·6 × 3·1
81	3·14	3·75	2·97	1·56	1·15	3·89	·80	310	6·11	4·82	3·85	2·82	14·19	15·50	4·28	10·8 × 3·6	7·7 × 3·1
82	3·18	3·79	3·00	1·58	1·16	3·94	·81	315	6·15	4·85	3·89	2·85	14·40	15·75	4·36	11·0 × 3·6	7·8 × 3·2
83	3·22	3·84	3·04	1·60	1·18	3·99	·82	320	6·19	4·88	3·94	2·88	14·61	16·00	4·44	11·2 × 3·6	7·9 × 3·2
84	3·25	3·88	3·07	1·62	1·19	4·04	·83	325	6·22	4·91	3·99	2·91	14·82	16·25	4·52	11·4 × 3·7	8·0 × 3·3
85	3·29	3·93	3·11	1·64	1·21	4·08	·84	330	6·25	4·94	4·04	2·94	15·03	16·50	4·60	11·6 × 3·7	8·2 × 3·3
86	3·32	3·97	3·14	1·66	1·22	4·13	·85	335	6·28	4·97	4·08	2·97	15·24	16·75	4·68	11·8 × 3·7	8·3 × 3·4
87	3·36	4·02	3·18	1·68	1·23	4·18	·86	340	6·31	5·00	4·12	3·00	15·45	17·00	4·76	12·0 × 3·7	8·4 × 3·4
88	3·40	4·07	3·21	1·70	1·25	4·22	·87	345	6·34	5·03	4·16	3·03	15·66	17·25	4·84	12·2 × 3·7	8·5 × 3·5
89	3·44	4·11	3·25	1·72	1·26	4·27	·88	350	6·37	5·06	4·20	3·06	15·87	17·50	4·92	12·4 × 3·7	8·6 × 3·5
90	3·48	4·16	3·29	1·74	1·27	4·32	·89	355	6·40	5·09	4·24	3·09	16·08	17·75	5·00	12·6 × 3·8	8·8 × 3·6
91	3·52	4·20	3·32	1·76	1·29	4·36	·90	360	6·43	5·12	4·28	3·12	16·29	18·00	5·08	12·8 × 3·8	8·9 × 3·6
92	3·56	4·25	3·36	1·78	1·30	4·41	·91	365	6·47	5·15	4.32	3·15	16·50	18·25	5·16	13·0 × 3·8	9·0 × 3·7
93	3·60	4·29	3·40	1·80	1·32	4·46	·92	370	6·50	5·18	4·36	3·18	16·71	18·50	5·24	13·2 × 3·9	9·1 × 3·7
94	3·64	4·34	3·43	1·82	1·33	4·51	·93	375	6·53	5·21	4·40	3·21	16·92	18·75	5·32	13·4 × 3·9	9·3 × 3·8
95	3·68	4·38	3·47	1·84	1·34	4·56	·94	380	6·56	5·24	4·44	3·24	17·13	19·00	5·40	13·6 × 3·9	9·5 × 3·8
96	3·72	4·43	3·50	1·86	1·35	4·61	·95	385	6·59	5·27	4·48	3·27	17·34	19·25	5·48	13·8 × 4·0	9·6 × 3·9
97	3·75	4·47	3·53	1·88	1·37	4·66	·96	390	6·62	5·30	4·52	3·30	17·55	19·50	5·56	14·0 × 4·0	9·7 × 3·9
98	3·79	4·51	3·57	1·90	1·39	4·70	·97	395	6·65	5·33	4·56	3·33	17·76	19·75	5·64	14·2 × 4·0	9.8 × 4·
99	3·83	4·57	3·61	1·92	1·40	4·75	·98	400	6·68	5·36	4·60	3·36	17·97	20·00	5·72	14·4 × 4·0	9·9 × 4·
100	3·87	4·62	3·66	1·93	1·41	4·80	·99										

Diameter of Cylinder, in Inches.	Area of each Steam Port, in Square Inches.															Diameter of Cylinder, in Inches.
	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	Length of Stroke in Feet.
20	12·89	14·11	15·33	16·55	17·78	19·00	20·22	21·44	22·66	23·88	25·10	26·33	27·55	28·77	30·00	20
21	13·44	14·79	16·15	17·51	18·88	20·23	21·59	22·95	24·31	25·67	27·02	28·39	29·75	31·11	32·47	21
22	13·99	15·47	16·97	18·47	19·98	21·46	22·96	24·46	25·96	27·46	28·94	30·45	31·95	33·45	34·94	22
23	14·54	16·15	17·79	19·43	21·08	22·69	24·33	25·97	27·61	29·25	30·86	32·51	34·15	35·79	37·41	23
24	15·09	16·84	18·62	20·40	22·18	23·93	25·71	27·49	29·26	31·04	32·78	34·57	36·35	38·13	39·88	24
25	15·64	17·55	19·46	21·37	23·28	25·19	27·10	29·01	30·92	32·83	34·74	36·65	38·56	40·47	42·37	25
26	16·31	18·39	20·47	22·54	24·62	26·70	28·78	30·85	32·03	35·01	37·09	39·17	41·24	43·32	45·39	26
27	16·98	19·23	21·47	23·71	25·96	28·21	30·46	32·69	34·04	37·19	39·44	41·69	43·92	46·17	48·41	27
28	17·65	20·07	22·48	24·88	27·30	29·72	32·14	34·53	36·05	39·37	41·79	44·21	46·60	49·02	51·43	28
29	18·32	20·91	23·49	26·06	28·64	31·23	33·82	36·37	38·07	41·55	44·15	46·73	49·29	51·88	54·45	29
30	19·00	21·75	24·50	27·25	30·00	32·75	35·50	38·25	41·00	43·75	46·50	49·25	52·00	54·75	57·49	30
31	19·79	22·74	25·69	28·74	31·58	34·53	37·48	40·43	43·38	46·32	49·27	52·22	55·17	58·12	61·06	31
32	20·58	23·73	26·88	30·23	33·16	36·31	39·46	42·61	45·76	48·89	52·04	55·19	58·34	61·49	64·63	32
33	21·37	24·72	28·07	31·72	34·74	38·09	41·44	44·79	48·14	51·46	54·81	58·16	61·51	64·86	68·20	33
34	22·17	25·71	29·26	33·21	36·32	39·87	43·42	46·97	50·52	54·04	57·58	61·13	64·68	68·23	71·77	34
35	22·97	26·71	30·45	34·71	37·94	41·68	45·42	49·16	52·90	56·64	60·38	64·12	67·86	71·60	75·37	35
36	23·88	27·85	31·82	36·21	39·77	43·74	47·71	51·68	55·65	59·62	63·59	67·56	71·53	75·50	79·49	36
37	24·80	28·99	33·19	37·71	41·60	45·80	50·00	54·20	58·40	62·60	66·80	71·00	75·20	79·40	83·61	37
38	25·71	30·13	34·56	39·21	43·43	47·86	52·29	56·72	61·15	65·58	70·01	74·44	78·87	83·30	87·73	38
39	26·63	31·28	35·93	40·71	45·26	49·93	54·58	59·24	63·90	68·56	73·22	77·88	82·54	87·20	91·86	39
40	27·56	32·44	37·33	42·21	47·11	52·00	56·89	61·78	66·67	71·56	76·45	81·34	86·23	91·12	95·99	40
41	28·59	33·74	38·89	44·03	49·18	54·33	59·48	64·63	69·78	74·93	80·08	85·23	90·38	95·52	100·66	41
42	29·62	35·04	40·45	45·85	51·25	56·66	62·07	67·48	72·89	78·30	83·71	89·12	94·53	99·93	105·33	42
43	30·66	36·34	42·01	47·67	53·32	58·99	64·66	70·33	76·00	81·67	87·34	93·01	98·68	104·34	110·00	43
44	31·69	37·64	43·57	49·49	55·40	61·33	67·27	73·19	79·12	85·05	90·97	96·91	102·84	108·75	114·68	44
45	32·75	38·94	45·13	51·32	57·50	63·69	69·88	76·06	82·25	88·44	94·63	100·82	107·01	113·20	119·37	45
46	33·91	40·39	46·87	53·35	59·82	66·30	72·78	79·25	85·73	92·21	98·69	105·17	111·65	118·13	124·59	46
47	35·07	41·84	48·61	55·38	62·14	68·91	75·68	82·44	89·21	95·98	102·75	109·52	116·29	123·06	129·81	47
48	36·23	43·29	50·35	57·41	64·46	71·52	78·58	85·64	92·69	99·75	106·81	113·87	120·93	127·99	135·03	48
49	37·39	44·74	52·09	59·44	66·78	74·14	81·48	88·84	96·17	103·53	110·87	118·22	125·57	132·92	140·25	49
50	38·56	46·19	53·83	61·47	69·11	76·75	84·39	92·03	99·67	107·31	114·94	122·58	130·22	137·86	145·49	50
51	39·84	47·79	55·75	63·71	71·66	79·69	87·71	95·73	103·75	111·77	119·78	127·80	135·82	143·84	151·86	51
52	41·12	49·39	57·67	65·95	74·22	82·63	91·03	99·43	107·83	116·23	124·62	133·02	141·42	149·82	158·23	52
53	42·40	50·99	59·59	68·19	76·78	85·57	94·35	103·13	111·91	120·69	129·46	138·25	147·03	155·80	164·60	53
54	43·68	52·60	61·52	70·43	79·35	88·52	97·67	106·84	115·99	125·15	134·30	143·47	152·64	161·79	170·98	54
55	44·97	54·21	63·45	72·69	81·94	91·48	101·02	110·56	120·10	129·64	139·18	148·72	158·26	167·80	177·37	55
56	46·37	55·96	65·56	75·15	84·75	94·58	104·41	114·25	124·08	133·91	143·74	153·57	163·40	173·24	183·09	56
57	47·78	57·72	67·67	77·61	87·56	97·68	107·80	117·93	128·06	138·18	148·30	158·42	168·54	178·68	188·81	57
58	49·18	59·48	69·78	80·07	90·37	100·78	111·19	121·61	132·04	142·45	152·86	163·27	173·68	184·12	194·54	58
59	50·59	61·23	71·89	82·53	93·18	103·89	114·59	125·30	136·02	146·72	157.43	168·13	178·84	189·56	200·27	59
60	52·00	63·00	74·00	85·00	96·00	107·00	118·00	129·00	140·00	151·00	162·00	173·00	184·00	195·00	206·00	60
61	53·53	64·50	75·48	86·46	97·44	108·83	120·22	131·61	143·00	154·39	165·78	177·17	188·57	199·95	211·35	61
62	55·06	66·00	76·96	87·92	98·88	110·66	122·44	134·22	146·01	157·79	169·56	181·34	193·13	204·90	216·70	62
63	56·59	67·51	78·44	89·38	100·32	112·50	124·66	136·83	149·02	161·18	173·35	185·52	197·69	209·85	222·05	63
64	58·12	69·02	79·92	90·84	101·76	114·34	126·89	139·44	152·03	164·58	177·13	189·70	202·26	214·80	227·40	64
65	59·64	70·54	81·44	92·34	103·24	116·19	129·14	142·09	155·04	167·99	180·94	193·89	206·84	219·79	232·75	65
66	61·29	73·00	84·71	96·43	108·14	121·49	134·86	148·21	161·56	174·91	188·27	201·62	214·98	228·33	241·70	66
67	62·94	75·46	87·98	100·52	113·04	126·80	140·58	154·33	168·08	181·83	195·60	209·36	223·12	236·87	250·65	67
68	64·59	77·92	91·25	104·61	117·94	132·11	146·29	160·45	174·60	188·76	202·93	217·09	231·26	245·41	259·60	68
69	66·24	80·38	94·52	108·70	122·84	137·42	152·00	166·57	181·12	195·69	210·26	224·83	239·40	253·95	268·55	69
70	67·89	82·86	97·83	112·80	127·78	142·75	157·72	172·69	187·66	202·63	217·60	232·57	247·54	262·51	277·50	70
71	69·66	85·08	100·49	115·90	131·32	146·73	162·15	177·56	192·98	208·39	223·80	239·22	254·63	269·32	284·03	71
72	71·43	87·30	103·15	119·00	134·86	150·71	166·58	182·43	198·30	214·15	230·01	245·87	261·72	276·13	290·56	72
73	73·20	89·52	105·81	122·10	138·40	154·69	171·01	187·30	203·62	219·91	236·22	252·52	268·81	282·95	297·09	73
74	74·98	91·73	108·47	125·21	141·94	158·67	175·44	192·18	208·94	225·67	242·43	259·17	275·91	289·77	303·63	74
75	76·75	93·94	111·13	128·32	145·50	162·69	179·88	197·07	214·26	231·45	248·64	265·83	283·02	296·59	310·17	75
76	78·64	96·30	113·97	131·63	149·28	166·95	184·61	202·27	219·94	237·60	255·26	272·92	290·59	305·36	320·13	76
77	80·53	98·66	116·81	134·94	153·07	171·21	189·34	207·47	225·62	243·75	261·89	280·01	298·16	314·13	330·09	77
78	82·42	101·02	119·65	138·25	156·85	175·47	194·07	212·67	231·30	249·90	268·51	287·10	305·73	322·90	340·05	78
79	84·31	103·39	122·49	141·56	160·64	179·73	198·80	217·88	236·98	256·05	275·14	294·19	313·30	331·67	350·02	79
80	86·22	105·77	125·33	144·88	164·44	183·99	203·55	223·10	242·66	262·21	281·77	301·32	320·88	340·44	360·00	80
81	88·24	108·29	128·36	148·41	168·47	188·53	208·59	228·65	248·71	268·76	288·83	308·88	328·95	349·01	369·07	81
82	90·26	110·81	131·38	151·94	172·50	193·07	213·63	234·25	254·76	275·31	295·89	316·44	337·02	357·58	378·14	82
83	92·27	113·33	134·40	155·47	176·53	197·61	218·67	239·80	260·81	281·86	302·95	324·00	345·09	366·16	387·21	83
84	94·28	115·85	137·42	159·00	180·56	202·15	223·71	245·35	266·86	288·42	310·01	331·57	353·16	374·74	396·29	84
85	96·30	118·38	140·46	162·54	184·61	206·69	228·77	250·85	272·92	295·00	317·08	339·16	361·24	383·32	405·37	85
86	98·44	121·05	143·66	166·28	188·88	211·50	234·11	256·73	279·33	301·95	324·56	347·17	369·79	392·40	414·99	86
87	100·58	123·72	146·86	170·02	193·16	216·31	239·45	262·61	285·74	308·90	332·04	355·18	378·34	401·48	424·61	87
88	102·72	126·39	150·06	173·76	197·43	221·12	244·79	268·49	292·15	315·85	339·52	363·19	386·89	410·56	434·24	88
89	104·86	129·06	153·27	177·50	201·70	225·94	250·14	274·37	298·56	322·80	347·00	371·20	395·44	419·65	443·82	89
90	107·00	131·75	156·50	181·25	206·00	230·75	255·50	280·25	305·00	329·75	354·50	379·25	404·00	428·75	453·50	90
91	109·26	134·57	159·89	185·20	210·52	235·83	261·15	286·46	311·78	337·09	362·41	387·72	413·04	438·35	463·67	91
92	111·52	137·39	163·28	189·15	215·04	240·91	266·80	292·67	318·56	344·44	370·32	396·19	422·08	447·95	473·84	92
93	113·78	140·21	166·67	193·10	219·56	245·99	272·45	298·88	325·34	351·78	378·23	404·66	431·12	457·55	484·01	93
94	116·04	143·03	170·06	197·05	224·08	251·07	278·10	305·09	332·12	359·13	386·14	413·13	440·16	467·16	494·19	94
95	118·31	145·88	173·45	201·02	228·61	256·18	283·76	311·33	338·91	366·48	394·06	421·64	449·21	476·78	504·37	95
96	120·69	148·85	177·02	205·19	233·37	261·54	289·71	317·88	346·06	374·22	402·40	430·57	458·74	486·88	515·09	96
97	123·07	151·82	180·59	209·36	238·13	266·90	295·66	324·43	353·21	381·96	410·74	439·50	468·28	496·99	525·82	97
98	125·45	154·79	184·16	213·53	242·89	272·26	301·61	330·98	360·36	389·70	419·08	448·43	477·82	507·09	536·55	98
99	127·83	157·76	187·73	217·70	247·65	277·62	307·57	337·53	367·51	397·45	427·42	457·37	487·36	517·19	547·27	99
100	130·22	160·77	191·33	221·88	252·44	282·99	313·55	344·10	374·66	405·21	435·77	466·32	496·90	527·30	558·00	100

Diameter of Cylinder, in Inches.	Diameter of Branch Steam Pipe, in Inches.															Diameter of Cylinder, in Inches.
	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	
20	3·76	3·90	4·02	4·14	4·26	4·38	4·49	4·60	4·71	4·81	4·91	5·01	5·11	5·21	5·30	20
21	3·82	3·97	4·10	4·23	4·36	4·49	4·61	4·73	4·84	4·95	5·06	5·17	5·27	5·38	5·48	21
22	3·88	4·04	4·18	4·32	4·46	4·60	4·73	4·86	4·97	5·09	5·21	5·33	5·43	5·55	5·66	22
23	3·94	4·11	4·26	4·41	4·56	4·71	4·85	4·99	5·11	5·23	5·36	5·49	5·60	5·72	5·84	23
24	4·00	4·18	4·34	4·50	4·66	4·82	4·97	5·12	5·25	5·37	5·51	5·65	5·77	5·89	6·02	24
25	4·06	4·25	4·42	4·59	4·76	4·93	5·09	5·25	5·39	5·51	5·66	5·81	5·94	6·06	6·20	25
26	4·12	4·32	4·50	4·69	4·87	5·04	5·21	5·38	5·53	5·66	5·81	5·97	6·11	6·23	6·38	26
27	4·18	4·39	4·59	4·79	4·98	5·15	5·33	5·51	5·67	5·81	5·97	6·13	6·28	6·41	6·56	27
28	4·24	4·46	4·68	4·89	5·09	5·27	5·45	5·64	5·81	5·96	6·13	6·29	6·45	6·59	6·74	28
29	4·31	4·54	4·77	4·99	5·20	5·39	5·58	5·77	5·95	6·11	6·29	6·45	6·62	6·77	6·92	29
30	4·38	4·62	4·86	5·09	5·31	5·51	5·71	5·90	6·09	6·27	6·45	6·62	6·79	6·95	7·11	30
31	4·45	4·70	4·95	5·19	5·42	5·63	5·84	6·04	6·24	6·43	6·61	6·79	6·97	7·13	7·30	31
32	4·52	4·78	5·04	5·29	5·53	5·75	5·97	6·18	6·39	6·59	6·77	6·96	7·15	7·31	7·49	32
33	4·59	4·86	5·14	5·40	5·65	5·88	6·10	6·31	6·54	6·75	6·93	7·13	7·33	7·50	7·68	33
34	4·66	4·94	5·24	5·51	5·77	6·01	6·23	6·45	6·69	6·91	7·10	7·30	7·51	7·69	7·87	34
35	4·73	5·03	5·34	5·62	5·89	6·14	6·37	6·59	6·84	7·07	7·27	7·47	7·69	7·88	8·06	35
36	4·80	5·12	5·44	5·73	6·01	6·27	6·51	6·74	6·99	7·23	7·44	7·64	7·87	8·07	8·25	36
37	4·87	5·21	5·54	5·84	6·13	6·40	6·65	6·89	7·14	7·39	7·61	7·82	8·05	8·26	8·45	37
38	4·95	5·30	5·64	5·95	6·25	6·53	6·79	7·04	7·29	7·55	7·78	8·00	8·23	8·45	8·65	38
39	5·03	5·39	5·74	6·06	6·37	6·66	6·93	7·19	7·45	7·71	7·95	8·18	8·42	8·64	8·85	39
40	5·11	5·48	5·84	6·17	6·49	6·79	7·07	7·35	7·62	7·88	8·12	8·36	8·60	8·83	9·05	40
41	5·19	5·57	5·94	6·28	6·61	6·92	7·21	7·50	7·77	8·04	8·29	8·54	8·78	9·02	9·25	41
42	5·27	5·66	6·04	6·39	6·73	7·05	7·35	7·65	7·93	8·20	8·46	8·72	8·96	9·21	9·45	42
43	5·35	5·75	6·14	6·50	6·85	7·18	7·49	7·80	8·09	8·36	8·63	8·90	9·15	9·40	9·65	43
44	5·43	5·84	6·24	6·62	6·97	7·31	7·63	7·95	8·25	8·53	8·80	9·08	9·34	9·59	9·85	44
45	5·51	5·93	6·34	6·74	7·10	7·44	7·73	8·10	8·41	8·70	8·97	9·26	9·53	9·78	10·05	45
46	5·59	6·02	6·45	6·86	7·23	7·58	7·87	8·25	8·57	8·87	9·15	9·44	9·72	9·97	10·25	46
47	5·67	6·11	6·56	6·98	7·36	7·72	8·02	8·40	8·73	9·04	9·33	9·62	9·91	10·17	10·45	47
48	5·75	6·21	6·67	7·10	7·49	7·86	8·17	8·55	8·89	9·21	9·51	9·80	10·10	10·37	10·65	48
49	5·83	6·31	6·78	7·22	7·62	8·00	8·32	8·71	9·05	9·38	9·69	9·99	10·29	10·57	10·85	49
50	5·92	6·41	6·89	7·34	7·75	8·14	8·51	8·87	9·21	9·54	9·87	10·18	10·48	10·77	11·05	50
51	6·00	6·51	7·00	7·46	7·88	8·28	8·65	9·02	9·37	9·71	10·04	10·36	10·67	10·96	11·26	51
52	6·09	6·61	7·11	7·58	8·01	8·42	8·84	9·17	9·53	9·88	10·21	10·54	10·86	11·15	11·46	52
53	6·18	6·72	7·22	7·70	8·14	8·56	8·99	9·32	9·69	10·05	10·39	10·72	11·05	11·34	11·67	53
54	6·27	6·82	7·33	7·82	8·27	8·70	9·14	9·47	9·85	10·22	10·57	10·90	11·24	11·54	11·87	54
55	6·36	6·92	7·44	7·94	8·40	8·84	9·29	9·62	10·01	10·39	10·75	11·08	11·43	11·74	12·07	55
56	6·45	7·02	7·55	8·06	8·53	8·98	9·44	9·77	10·17	10·56	10·93	11·26	11·62	11·94	12·28	56
57	6·54	7·13	7·66	8·18	8·66	9·12	9·59	9·92	10·34	10·73	11·11	11·45	11·81	12·14	12·48	57
58	6·63	7·23	7·77	8·30	8·79	9·26	9·74	10·08	10·51	10·90	11·29	11·64	12·00	12·34	12·68	58
59	6·71	7·33	7·88	8·42	8·92	9·40	9·89	10·24	10·68	11·07	11·47	11·83	12·19	12·54	12·88	59
60	6·78	7·43	8·00	8·54	9·05	9·54	10·00	10·44	10·85	11·25	11·65	12·03	12·39	12·74	13·09	60
61	6·87	7·53	8·11	8·66	9·18	9·68	10·14	10·59	11·01	11·42	11·82	12·21	12·58	12·94	13·29	61
62	6·96	7·63	8·22	8·78	9·31	9·82	10·28	10·74	11·17	11·59	11·99	12·39	12·77	13·14	13·49	62
63	7·05	7·73	8·33	8·90	9·44	9·96	10·43	10·89	11·33	11·76	12·17	12·57	12·96	13·34	13·69	63
64	7·14	7·82	8·44	9·02	9·57	10·10	10·58	11·04	11·49	11·93	12·35	12·75	13·15	13·55	13·89	64
65	7·23	7·92	8·55	9·14	9·70	10·24	10·73	11·20	11·65	12·10	12·53	12·93	13·34	13·75	14·10	65
66	7·32	8·02	8·66	9·26	9·83	10·38	10·88	11·36	11·82	12·27	12·71	13·12	13·53	13·95	14·31	66
67	7·41	8·12	8·77	9·38	9·96	10·52	11·03	11·52	11·99	12·44	12·89	13·31	13·72	14·15	14·52	67
68	7·50	8·22	8·88	9·51	10·09	10·66	11·18	11·68	12·16	12·62	13·07	13·50	13·92	14·35	14·73	68
69	7·59	8·32	9·00	9·64	10·23	10·80	11·33	11·84	12·33	12·80	13·25	13·69	14·12	14·55	14·94	69
70	7·67	8·42	9·12	9·77	10·37	10·94	11·48	12·00	12·50	12·98	13·43	13·88	14·32	14·75	15·15	70
71	7·76	8·52	9·23	9·89	10·50	11·08	11·63	12·16	12·66	13·15	13·61	14·07	14·51	14·96	15·35	71
72	7·85	8·62	9·34	10·01	10·63	11·23	11·78	12·32	12·83	13·32	13·79	14·26	14·70	15·16	15·56	72
73	7·94	8·72	9·45	10·13	10·76	11·37	11·93	12·48	13·00	13·49	13·97	14·45	14·89	15·36	15·76	73
74	8·03	8·82	9·56	10·25	10·89	11·52	12·08	12·64	13·17	13·66	14·15	14·64	15·08	15·56	15·97	74
75	8·12	8·93	9·68	10·37	11·02	11·66	12·23	12·80	13·34	13·84	14·33	14·83	15·28	15·76	16·18	75
76	8·21	9·04	9·80	10·50	11·16	11·81	12·38	12·96	13·51	14·02	14·51	15·02	15·48	15·96	16·39	76
77	8·30	9·15	9·92	10·63	11·30	11·95	12·54	13·12	13·68	14·20	14·70	15·21	15·68	16·16	16·60	77
78	8·39	9·25	10·04	10·76	11·44	12·10	12·70	13·28	13·85	14·38	14·89	15·40	15·88	16·37	16·81	78
79	8·48	9·36	10·16	10·89	11·58	12·24	12·86	13·44	14·02	14·56	15·08	15·59	16·08	16·57	17·02	79
80	8·59	9·46	10·28	11·02	11·73	12·39	13·02	13·61	14·19	14·74	15·27	15·78	16·28	16·77	17·23	80
81	8·68	9·56	10·39	11·14	11·86	12·53	13·17	13·77	14·35	14·91	15·45	15·97	16·47	16·97	17·43	81
82	8·77	9·66	10·50	11·26	11·99	12·67	13·32	13·93	14·52	15·08	15·63	16·16	16·66	17·17	17·64	82
83	8·86	9·76	10·61	11·38	12·12	12·81	13·47	14·09	14·69	15·25	15·81	16·35	16·85	17·38	17·85	83
84	8·95	9·86	10·72	11·51	12·25	12·95	13·62	14·26	14·86	15·42	15·99	16·54	17·04	17·58	18·06	84
85	9·04	9·97	10·84	11·64	12·39	13·09	13·77	14·42	15·03	15·60	16·17	16·73	17·24	17·78	18·27	85
86	9·13	10·08	10·96	11·77	12·53	13·24	13·92	14·58	15·20	15·78	16·35	16·92	17·44	17·98	18·48	86
87	9·22	10·19	11·08	11·90	12·67	13·39	14·07	14·74	15·37	15·96	16·53	17·11	17·64	18·19	18·69	87
88	9·31	10·30	11·20	12·03	12·81	13·54	14·23	14·90	15·54	16·14	16·72	17·30	17·84	18·39	18·90	88
89	9·41	10·41	11·32	12·16	12·95	13·69	14·39	15·07	15·71	16·32	16·91	17·49	18·04	18·59	19·11	89
90	9·52	10·52	11·44	12·29	13·09	13·84	14·55	15·24	15·88	16·50	17·10	17·68	18·24	18·79	19·32	90
91	9·61	10·62	11·55	12·41	13·22	13·98	14·70	15·40	16·04	16·67	17·28	17·87	18·43	18·99	19·52	91
92	9·70	10·72	11·67	12·54	13·35	14·12	14·85	15·56	16·21	16·84	17·46	18·06	18·62	19·19	19·73	92
93	9·79	10·82	11·79	12·67	13·49	14·26	15·00	15·72	16·38	17·02	17·64	18·25	18·81	19·40	19·94	93
94	9·88	10·93	11·91	12·80	13·63	14·40	15·15	15·88	16·55	17·20	17·82	18·44	19·01	19·60	20·15	94
95	9·97	11·04	12·03	12·93	13·77	14·55	15·30	16·04	16·72	17·38	18·01	18·63	19·21	19·80	20·36	95
96	10·06	11·15	12·25	13·06	13·91	14·70	15·45	16·20	16·89	17·56	18·20	18·82	19·41	20·00	20·57	96
97	10·15	11·26	12·27	13·19	14·05	14·85	15·61	16·36	17·06	17·74	18·39	19·01	19·61	20·20	20·78	97
98	10·24	11·37	12·39	13·32	14·19	15·00	15·77	16·52	17·23	17·92	18·58	19·20	19·81	20·41	20·99	98
99	10·33	11·48	12·51	13·45	14·33	15·15	15·93	16·68	17·40	18·10	18·77	19·40	20·01	20·61	21·20	99
100	10·47	11·59	12·63	13·58	14·47	15·30	16·09	16·84	17·57	18·28	18·96	19·60	20·21	20·81	21·41	100

{ Length of Stroke in Feet.

Horse Power.	Diameter of Waste Water Pipe, in Inches.	Area of Fort Valve Passage, in Square Inches.	Area of Injection Pipe, in Square Inches.	Diameter of Feed Pipe, in Inches.	Diameter of Waste Steam Pipe, in Inches.	Diameter of Safety Valve when only One used.	Diameter of each Safety Valve when Two used.	Diameter of each Safety Valve when Three used.	Diameter of each Safety Valve when Four used.	Horse Power.	Diameter of Waste Steam Pipe.	Diameter of Safety Valve when only One used.	Diameter of each Safety Valve when Two used.	Diameter of each Safety Valve when Three used.	Diameter of each Safety Valve when Four used.
5	2·69	17	3·15	1·79	4·33	5	3·54	2·89	2·5	405	12·99	15·00	10·60	8·66	7·50
10	3·32	26	3·49	1·84	4·52	5·23	3·70	3·02	2·61	410	13·07	15·09	10·66	8·71	7·54
15	3·94	35	3·84	1·89	4·71	5·45	3·86	3·14	2·71	415	13·14	15·17	10·72	8·76	7·58
20	4·56	44	4·18	1·94	4·90	5·66	4·02	3·26	2·81	420	13·21	15·25	10·78	8·81	7·62
25	5·18	53	4·53	1·99	5·08	5·86	4·17	3·38	2·92	425	13·28	15·33	10·84	8·86	7·66
30	5·80	62	4·87	2·04	5·26	6·05	4·32	3·50	3·02	430	13·35	15·41	10·90	8·91	7·70
35	6·42	71	5·22	2·09	5·43	6·24	4·47	3·62	3·12	435	13·42	15·49	10·96	8·96	7·74
40	7·04	80	5·56	2·13	5·60	6·42	4·62	3·74	3·23	440	13·49	15·57	11·02	9·00	7·78
45	7·66	89	5·91	2·18	5·77	6·60	4·76	3·86	3·33	445	13·56	15·65	11·08	9·05	7·82
50	8·28	98	6·25	2·23	5·94	6·80	4·90	3·98	3·43	450	13·63	15·73	11·13	9·09	7·86
55	8·90	107	6·60	2·28	6·12	7·07	5·00	4·08	3·53	455	13·70	15·81	11·18	9·13	7·90
60	9·50	116	6·94	2·32	6·26	7·23	5·12	4·18	3·61	460	13·77	15·89	11·24	9·18	7·94
65	10·06	125	7·29	2·36	6·40	7·39	5·24	4·28	3·69	465	13·84	15·97	11·29	9·23	7·98
70	10·56	134	7·63	2·40	6·54	7·55	5·35	4·37	3·77	470	13·91	16·05	11·35	9·28	8·02
75	10·96	143	7·98	2·44	6·68	7·71	5·46	4·46	3·85	475	13·98	16·13	11·40	9·33	8·06
80	11·31	152	8·32	2·48	6·82	7·87	5·57	4·55	3·93	480	14·05	16·20	11·45	9·37	8·10
85	11·61	161	8·67	2·52	6·96	8·03	5·68	4·64	4·01	485	14·12	16·27	11·50	9·41	8·14
90	11·89	170	9·01	2·56	7·10	8·19	5·79	4·73	4·09	490	14·18	16·34	11·55	9·45	8·18
95	12·09	179	9·36	2·60	7·24	8·35	5·90	4·82	4·17	495	14·24	16·41	11·60	9·49	8·21
100	12·19	188	9·70	2·64	7·31	8·51	6·01	4·91	4·25	500	14·30	16·48	11·65	9·52	8·24
105	12·29	197	10·05	2·68	7·50	8·66	6·12	5·00	4·33	505	14·36	16·55	11·70	9·56	8·27
110	12·56	206	10·39	2·72	7·62	8·80	6·22	5·08	4·40	510	14.43	16·63	11·76	9·61	8·31
115	12·83	215	10·74	2·76	7·74	8·94	6·32	5·16	4·47	515	14·50	16·71	11·81	9·66	8·35
120	13·10	224	11·08	2·80	7·86	9·08	6·42	5·24	4·54	520	14·57	16·79	11·87	9·71	8·39
125	13·37	233	11·43	2·84	7·98	9·22	6·52	5·32	4·61	525	14·64	16·87	11·92	9·76	8·43
130	13·64	242	11·77	2·88	8·10	9·36	6·62	5·40	4·68	530	14·70	16·95	11·98	9·80	8·47
135	13·91	251	12·12	2·91	8·22	9·50	6·71	5·48	4·75	535	14·76	17·03	12·03	9·84	8·51
140	14·18	260	12·46	2·94	8·33	9·63	6·80	5·55	4·82	540	14·83	17·11	12·09	9·88	8·55
145	14·44	269	12·81	2·97	8·44	9·76	6·89	5·62	4·88	545	15·00	17·18	12·14	9·92	8·59
150	14·70	278	13·15	3·00	8·55	9·89	6·98	5·69	4·94	550	15·07	17·25	12·20	9·96	8·63
155	14·97	287	13·50	3·03	8·66	10·00	7·07	5·77	5·00	555	15·13	17·32	12·25	10·00	8·66
160	15·20	296	13·84	3·07	8·76	10·12	7·16	5·84	5·06	560	15·19	17·40	12·30	10·05	8·70
165	15·43	305	14·19	3·11	8·86	10·24	7·25	5·91	5·12	565	15·25	17·47	12·35	10·09	8·73
170	15·65	314	14·53	3·14	8·96	10·36	7·34	5·98	5·18	570	15·31	17·54	12·40	10·13	8·77
175	15·87	323	14·88	3·17	9·06	10·48	7·43	6·05	5·24	575	15·37	17·61	12·45	10·17	8·80
180	16·09	332	15·22	3·20	9·16	10·60	7·52	6·12	5·30	580	15·43	17·68	12·50	10·21	8·84
185	16·31	341	15·57	3·23	9·26	10·72	7·60	6·19	5·36	585	15·49	17·75	12·55	10·25	8·87
190	16·53	350	15·91	3·26	9·36	10·84	7·68	6·26	5·42	590	15·55	17·82	12·60	10·29	8·91
195	16·75	359	16·26	3·29	9·46	10·95	7·76	6·33	5·48	595	15·61	17·89	12·65	10·33	8·94
200	16·97	368	16·60	3·32	9·56	11·06	7·84	6·40	5·54	600	15·67	17·96	12·70	10·37	8·98
205	17·19	377	16·95	3·35	9·66	11·18	7·91	6·46	5·59	605	15·73	18·03	12·75	10·41	9 01
210	17·39	386	17·29	3·38	9·76	11·29	7·99	6·53	5·65	610	15·79	18·10	12·80	10·45	9·05
215	17·59	395	17·64	3·41	9·86	11·40	8·07	6·59	5·71	615	15·85	18·17	12·85	10·49	9·09
220	17·79	404	17·98	3·44	9·96	11·51	8·15	6·65	5·77	620	15·91	18·24	12·90	10·53	9·13
225	17·99	413	18·33	3·47	10·06	11·62	8·23	6·71	5·82	625	15·97	18·31	12·95	10·57	9·17
230	18·19	422	18·67	3·50	10·15	11·73	8·31	6·77	5·87	630	16·03	18·38	13·00	10·61	9·20
235	18·39	431	19·02	3·53	10·24	11·84	8·39	6·83	5·92	635	16·09	18·45	13·05	10·65	9·23
240	18·58	440	19·36	3·56	10·33	11·95	8·46	6·89	5·97	640	16·15	18·51	13·10	10·69	9·26
245	18·77	449	19·71	3·59	10·42	12·05	8·53	6·95	6·02	645	16·20	18·57	13 15	10·73	9·29
250	18·97	458	20·05	3·61	10·51	12·15	8·60	7·01	6·07	650	16·26	18·63	13·19	10·77	9·32
255	19·16	467	20·40	3·63	10·60	12·25	8·67	7·07	6·12	655	16·32	18·70	13·23	10·80	9·35
260	19·34	476	20·74	3·66	10·69	12·35	8·74	7·13	6·17	660	16·38	18·77	13·28	10·84	9·39
265	19·52	485	21·09	3·69	10·78	12·45	8·81	7·19	6·22	665	16·44	18·83	13·33	10·88	9·43
270	19·70	494	21·43	3·72	10·87	12·55	8·88	7·25	6·27	670	16·49	18·90	13·38	10·92	9·47
275	19·88	503	21·78	3·74	10·96	12·65	8·95	7·31	6·32	675	16·54	18·96	13·43	10·96	9·50
280	20·06	512	22·12	3·77	11·05	12·75	9·02	7·37	6·37	680	16·59	19·03	13·48	11·00	9·53
285	20·24	521	22·47	3·80	11·13	12·85	9·09	7·43	6·42	685	16·65	19·10	13·53	11·04	9·56
290	20·42	530	22·81	3·82	11·21	12·95	9·16	7·49	6·47	690	16·71	19·17	13·58	11·08	9·59
295	20·60	539	23·16	3·85	11·29	13·05	9·23	7·54	6·52	695	16·77	19·24	13·62	11·12	9·62
300	20·78	548	23·50	3·88	11·37	13·14	9·29	7·59	6·57	700	16·83	19·31	13·66	11·15	9·65
305	20·95	557	23·85	3·90	11·45	13·23	9·35	7·64	6·61	705	16·88	19·37	13·70	11·18	9·68
310	21·12	566	24·19	3·93	11·53	13·33	9·42	7·70	6·66	710	16·94	19·44	13·74	11·22	9·72
315	21·29	575	24·54	3·95	11·61	13·42	9·48	7·76	6·71	715	16·99	19·51	13·79	11·26	9·76
320	21·46	584	24·88	3·98	11·69	13·51	9·55	7·82	6·76	720	17·05	19·58	13·83	11·30	9·79
325	21·63	593	25·23	4·00	11·77	13·60	9·61	7·87	6·81	725	17·10	19·64	13·88	11·34	9·82
330	21·80	602	25·57	4·03	11·85	13·69	9·68	7·92	6·86	730	17·16	19·70	13·92	11·38	9·85
335	21·97	611	25·92	4·05	11·93	13·78	9·74	7·97	6·91	735	17·21	19·76	13·97	11·42	9·88
340	22·14	620	26·26	4·07	12·01	13·87	9·81	8·02	6·96	740	17·27	19·82	14·01	11·46	9·91
345	22·30	629	26·61	4·10	12·09	13·96	9·87	8·07	7·00	745	17·32	19·88	14·06	11·49	9·94
350	22·46	638	26·95	4·12	12·17	14·05	9·94	8·12	7·04	750	17·38	19·94	14·10	11·52	9·97
355	22·61	647	27·30	4·14	12·25	14·14	10·00	8·17	7·07	755	17·43	20·00	14·15	11·55	10·00
360	22·77	656	27·64	4·16	12·33	14·23	10·06	8·22	7·12	760	17·48	20·07	14·20	11·59	10·03
365	22·93	665	27·99	4·19	12·41	14·32	10·12	8·27	7·17	765	17·54	20·13	14·24	11·62	10·06
370	23·09	674	28·33	4·21	12·49	14·41	10·18	8·32	7·22	770	17·59	20·19	14·28	11·66	10·09
375	23·24	683	28·68	4·23	12·57	14·50	10·24	8·37	7·26	775	17·65	20·25	14·33	11·69	10·12
380	23·40	692	29·02	4·26	12·63	14·59	10·30	8·42	7·30	780	17·70	20·31	14·37	11·73	10·15
385	23·55	701	29·37	4·28	12·70	14·68	10·36	8·47	7·34	785	17·75	20·37	14·41	11·76	10·18
390	23·70	710	29·72	4·31	12·77	14·76	10·42	8·52	7·38	790	17·80	20·43	14·45	11·80	10·21
395	23·85	719	30·06	4·35	12·84	14·84	10·48	8·57	7·42	795	17·85	20·49	14·49	11·83	10·24
400	24·00	728	30·41	4·37	12·91	14·92	10·54	8·62	7·46	800	17·90	20·55	14·53	11·87	10·27

Land Engines: — Depth of Web of Main Beam at Centre, in Inches.

N.B.—The total depth of Main Beam at centre is usually equal to the diameter of the Cylinder, and the thickness of the Web is $\frac{1}{108}$ the length of the Beam: the width of edge bead is about 1½ times the thickness of the Web.

Diameter of Cylinder, in Inches.	½ Length of Main Beam in Feet.															Diameter of Cylinder, in Inches.
	4	4½	5	5½	6	6½	7	7½	8	8½	9	9½	10	10½	11	
21	17·41	18·11	18·75	19·36	19·94	20·48	20·99	21·47	21·94	22·39	22·82	23·24	23·67	24·02	24·39	21
22	17·95	18·67	19·33	19·96	20·56	21·12	21·64	22·14	22·62	23·09	23·53	23·96	24·45	24·77	25·15	22
23	18·49	19·23	19·91	20·56	21·18	21·76	22·29	22·81	23·30	23·78	24·24	24·68	25·22	25·52	25·91	23
24	19·03	17·79	20·49	21·16	21·80	22·39	22·94	23·48	23·98	24·47	24·95	25·40	25·99	26·26	26·67	24
25	19·58	20·36	21·08	21·77	22·41	23·02	23·59	24·14	24·67	25·16	25·65	26·12	26·56	27·00	27·42	25
26	20·08	20·89	21·64	22·34	23·00	23·62	24·21	24·77	25·31	25·81	26·31	26·80	27·25	27·70	28·13	26
27	20·60	21·42	22·19	22·90	23·58	24·22	24·82	25·40	25·95	26·46	26·97	27·47	27·94	28·40	28·84	27
28	21·10	21·95	22·73	23·46	24·16	24·81	25·43	26·02	26·58	27·11	27·63	28·14	28·63	29·10	29·55	28
29	21·61	22·48	23·27	24·02	24·74	25·40	26·04	26·64	27·21	27·76	28·29	28·81	29·32	29·80	30·26	29
30	22·11	22·99	23·81	24·58	25·31	25·99	26·64	27·26	27·85	28·41	28·96	29·50	30·00	30·49	30·96	30
31	22·59	23·49	24·34	25·12	25·87	26·56	27·22	27·85	28·46	29·03	29·61	30·14	30·65	31·15	31·63	31
32	23·07	23·99	24·86	25·65	26·42	27·12	27·80	28·44	29·06	29·65	30·26	30·78	31·30	31·81	32·30	32
33	23·55	24·49	25·37	26·18	26·96	27·68	28·37	29·03	29·67	30·27	30·91	31·42	31·95	32·47	32·97	33
34	24·03	24·99	25·88	26·71	27·50	28·24	28·94	29·62	30·27	30·89	31·56	32·06	32·60	33·13	33·64	34
35	24·50	25·48	26·39	27·24	28·04	28·80	29·52	30·21	30·87	31·49	32·10	32·69	33·24	33·79	34·31	35
36	24·96	25·96	26·88	27·75	28·57	29·34	30·07	30·78	31·45	32·08	32·70	33·30	33·86	34·42	34·95	36
37	25·41	26·43	27·37	28·26	29·10	29·88	30·62	31·34	32·03	32·67	33·30	33·91	34·48	35·05	35·59	37
38	25·87	26·90	27·86	28·77	29·62	30·42	31·17	31·90	32·61	33·26	33·90	34·52	35·10	35·68	36·23	38
39	26·32	27·37	28·35	29·28	30·14	30·96	31·72	32·46	33·18	33·85	34·50	35·13	35·72	36·31	36·87	39
40	26·78	27·85	28·84	29·78	30·66	31·49	32·27	33·02	33·75	34·42	35·09	35·73	36·34	36·94	37·51	40
41	27·22	28·31	29·32	30·27	31·17	32·01	32·80	33·56	34·30	34·99	35·67	36·32	36·94	37·55	38·13	41
42	27·66	28·76	29·79	30·76	31·67	32·53	33·33	34·10	34·85	35·55	36·24	36·91	37·54	38·15	38·74	42
43	28·10	29·21	30·26	31·25	32·17	33·05	33·85	34·64	35·40	36·11	36·81	37·49	38·13	38·75	39·35	43
44	28·54	29·66	30·73	31·73	32·67	33·56	34·38	35·18	35·95	36·67	37·38	38·07	38·73	39·35	39·96	44
45	28·97	30·12	31·20	32·21	33·16	34·06	34·90	35·71	36·50	37·23	37·95	38·65	39·31	39·95	40·57	45
46	29·40	30·56	31·66	32·68	33·65	34·56	35·41	36·23	37·03	37·78	38·51	39·22	39·89	30·54	41·17	46
47	29·82	31·00	32·11	33·15	34·13	35·06	35·92	36·75	37·56	38·32	39·07	39·78	40·46	31·12	41·76	47
48	30·24	31·44	32·56	33·62	34·61	35·55	36·43	37·27	38·09	38·86	39·62	40·34	41·02	31·70	42·35	48
49	30·66	31·88	33·01	34·09	35·09	36·04	36·94	37·79	38·62	39·40	40·17	40·90	41·59	32·28	42·94	49
50	31·08	32·32	33·47	34·55	35·57	36·53	37·44	38·31	39·16	39·94	40·72	41·46	42·17	42·86	43·52	50
51	31·49	32·75	33·91	35·01	36·04	37·05	37·94	38·82	39·67	40·47	41·26	42·01	42·73	43·42	44·09	51
52	31·90	33·17	34·35	35·47	36·51	37·57	38·43	39·32	40·18	41·00	41·80	42·55	43·28	43·98	44·66	52
53	32·31	33·59	34·79	35·92	36·97	38·09	38·92	39·82	40·69	41·52	42·33	43·10	43·83	44·54	45·23	53
54	32·72	34·01	35·23	36·37	37·43	38·61	39·41	40·32	41·20	42·04	42·86	43·64	44·38	45·10	45·80	54
55	33·12	34·43	35·66	36·82	37·90	39·13	39·90	40·83	41·72	42·56	43·39	44·18	44·93	45·67	46·38	55
56	33·52	34·84	36·09	37·26	38·36	39·56	40·38	41·32	42·22	43·07	43·91	44·71	45·47	46·22	46·94	56
57	33·92	35·25	36·52	37·70	38·81	39·99	40·86	41·81	42·72	43·58	44·43	45·24	46·01	46·77	47·50	57
58	34·31	35·66	36·94	38·14	39·26	40·42	41·33	42·30	43·21	44·09	44·95	45·77	46·55	47·32	41·05	58
59	34·70	36·07	37·36	38·58	39·71	40·85	41·80	42·78	43·70	44·60	45·47	46·30	47·09	47·86	48·60	59
60	35·10	36·49	37·79	39·02	40·17	41·26	42·28	43·26	44·21	45·10	45·98	46·82	47·62	48·40	49·15	60
61	35·49	36·89	38·21	39·45	40·61	41·71	42·75	43·74	44·70	45·60	46·49	47·34	48·14	48·93	49·69	61
62	35·87	37·29	38·63	39·88	41·05	42·16	43·22	44·22	45·19	46·10	47·00	47·85	48·66	49·46	50·23	62
63	35·26	37·69	39·04	40·31	41·49	42·61	43·68	44·69	45·68	46·59	47·50	48·36	49·18	49·99	50·77	63
64	35·64	38·09	39·45	40·74	41·93	43·06	44·14	45·16	46·17	47·08	48·00	48·87	49·70	50·52	51·31	64
65	37·02	38·49	39·86	41·16	42·37	43·52	44·60	45·63	46·64	47·57	48·50	49·39	50·23	51·05	51·84	65
66	37·40	38·88	40·27	41·58	42·80	43·97	45·06	46·10	47·12	48·06	49·00	49·89	50·74	51·57	52·37	66
67	37·78	39·27	40·68	42·00	43·23	44·41	45·51	46·57	47·59	48·55	49·49	50·39	51·25	52·09	52·80	67
68	38·16	39·66	41·09	42·42	43·66	44·85	45·96	47·03	48·06	49·03	49·98	50·89	51·76	52·60	53·33	68
69	38·53	40·05	41·49	42·83	44·09	45·29	46·41	49·49	48·53	49·51	50·47	51·39	52·27	53·11	53·85	69
70	38 90	40·44	41·89	43·24	44·52	45·73	46·86	47·95	49·01	49·99	50·96	51·89	52·77	53·64	54·47	70
71	39·27	40·83	42·29	43·66	44·94	46·16	47·31	48·41	49·47	50·46	51·44	52·38	53·27	54·15	54·99	71
72	39·64	41·21	42·69	44·07	45·36	46·59	47·75	48·86	49·93	50·93	51·92	52·87	53·77	54·66	55·50	72
73	40·01	41·59	43·08	44·48	45·78	47·02	48·19	49·31	50·39	51·40	52·40	53·36	54·27	55·16	56·01	73
74	40·37	41·97	43·47	44·89	46·20	47·45	48·63	49·76	50·85	51·87	52·88	53·84	54·77	56·66	56·52	74
75	40·73	42·35	43·86	45·30	46·62	47·88	49·07	50·21	51·31	52·34	53·35	54·33	55·26	56·16	57·04	75
76	41·09	42·73	44·25	45·70	47·03	48·30	49·50	50·65	51·76	52·80	43·82	54·81	55·75	56·66	57·54	76
77	41·45	43·10	44·64	46·10	47·44	48·72	49·93	51·09	52·21	53·26	44·29	55·29	56·24	57·16	58·04	77
78	41·80	43·47	45·02	46·49	47·85	49·14	50·36	51·53	52·66	53·72	44·76	55·76	56·72	58·65	58·54	78
79	42·15	43·84	45·40	46·88	48·26	49·56	50·79	51·97	53·11	54·18	45·23	56·24	57·20	59·14	59·04	79
80	42·51	44·21	45·78	47·27	48·66	49·98	51·22	52·41	53·56	54·64	55·70	56·72	57·68	58·63	59·54	80
81	42·86	44·58	46·16	47·66	49·07	50·40	51·65	52·84	54·01	55·09	56·16	57·19	58·16	59·12	60·03	81
82	43·21	44·94	46·54	48·05	49·47	50·81	52·08	53·27	54·45	55·54	56·62	57·66	58·64	59·60	60·52	82
83	43·56	45·30	46·92	48·44	49·87	51·22	52·50	53·70	54·89	55·99	57·08	58·13	59·12	60·08	61·01	83
84	43·91	45·66	47·30	48·83	50·27	51·63	52·92	54·13	55·33	56·44	57·54	58·60	59·59	60·56	61·50	84
85	44·27	46·03	47·67	49·22	50·67	52·04	53·34	54·57	55·77	56·89	58·00	59·06	60·06	61·05	62·00	85
86	44·62	46·39	48·04	49·61	51·07	52·45	53·76	55·00	56·21	57·34	58·45	59·52	62·53	61·53	62·49	86
87	44·96	46·75	48·41	49·99	51·46	52·86	54·18	55·43	56·65	57·78	58·90	59·98	63·00	62·01	62·97	87
88	45·31	47·11	48·78	50·37	51·85	53·26	54·59	55·86	57·08	58·22	59·35	60·44	63·47	62·48	63·45	88
89	45·65	47·47	49·15	50·75	52·24	53·66	55·00	56·29	57·51	58·66	59·80	60·90	63·94	62·95	63·93	89
90	45·99	47·82	49·52	51·13	52·64	54·06	55·41	56·69	57·94	59·10	60·25	61·35	62·40	63·42	64·41	90
91	46·33	48·17	49·89	51·51	53·03	54·46	55·82	57·11	58·37	59·54	60·70	61·80	62·86	63·89	64·89	91
92	46·67	48·52	50·26	51·89	53·41	54·86	56·23	57·53	58·80	59·98	61·14	62·25	63·32	64·36	65·36	92
93	47·01	48·87	50·62	52·27	53·79	55·26	56·64	57·95	59·22	60·41	61·58	62·70	63·78	64·82	65·83	93
94	47·35	49·22	50·98	52·64	54·17	55·66	57·04	58·36	59·64	60·85	62·02	63·15	64·24	65·28	66·30	94
95	47·68	49·57	51·34	53·01	54·57	56·05	57·44	58·77	60·07	61·27	62·46	63·60	64·69	65·75	66·77	95
96	48·02	49·92	50·70	53·38	54·95	56·44	57·84	59·18	60·49	61·70	62·90	64·05	65·14	66·21	67·24	96
97	48·35	50·26	51·06	53·75	55·33	56·83	58·24	59·59	60·91	62·13	63·33	64·49	65·59	66·67	67·71	97
98	48·68	50·60	51·42	54·12	55·71	57·22	58·64	60·00	61·32	62·56	63·76	64·93	66·04	67·12	68·17	98
99	49·01	50·94	51·78	54·49	56·09	57·61	59·04	60·41	61·73	62·98	64·20	65·37	66·49	67·57	48·63	99
100	49·34	51·29	53·13	54·85	56·47	58·00	59·44	60·82	62·15	63·40	64·63	65·82	66·94	68·03	69·09	100

{Half Length of Main Beam in Feet.

Diameter of Cylinder in Inches.	LAND ENGINES. Depth of Main Beam at Ends, in Inches.															Diameter of Cylinder in Inches.
	4	4½	5	5½	6	6½	7	7½	8	8½	9	9½	10	10½	11	
21	6·96	7·24	7·50	7·74	7·98	8·19	8·40	8·59	8·78	8·96	9·13	9·30	9·46	9·61	9·76	21
22	7·17	7·46	7·72	7·97	8·21	8·43	8·65	8·84	9·04	9·22	9·40	9·57	9·74	9·89	10·05	22
23	7·38	7·68	7·94	8·20	8·44	8·67	8·90	9·09	9·30	9·48	9·67	9·84	10·02	10·17	10·34	23
24	7·59	7·90	8·16	8·43	8·68	8·91	9·15	9·34	9·56	9·74	9·94	10·12	10·30	10·46	10·63	24
25	7·80	8·12	8·38	9·66	8·92	9·15	9·40	9·60	9·82	10·01	10·21	10·40	10·58	10·75	10·92	25
26	8·01	8·34	8·60	8·89	9·16	9·40	9·65	9·86	10·08	10·28	10·48	10·68	10·86	11·04	11·21	26
27	8·22	8·56	8·82	9·12	9·40	9·65	9·90	10·12	10·34	10·55	10·75	10·96	11·14	11·33	11·50	27
28	8·43	8·78	9·04	9·35	9·64	9·90	10·15	10·38	10·60	10·82	11·02	11·24	11·42	11·62	11·79	28
29	8·64	9·00	9·26	9·53	9·88	10·15	10·40	10·64	10·87	11·09	11·29	11·52	11·71	11·91	12·08	29
30	8·84	9·20	9·52	9·83	10·12	10·40	10·66	10·90	11·14	11·36	11·58	11·80	12·00	12·20	12·38	30
31	9·02	9·39	9·72	10·03	10·33	10·62	10·88	11·13	11·37	11·60	11·82	12·04	12·25	12·45	12·64	31
32	9·20	9·58	9·92	10·23	10·54	10·84	11·10	11·36	11·60	11·84	12·06	12·29	12·50	12·70	12·90	32
33	9·38	9·76	10·12	10·44	10·75	11·06	11·32	11·59	11·83	12·08	12·30	12·54	12·75	12·96	13·16	33
34	9·57	9·95	10·32	10·65	10·96	11·28	11·54	11·82	12·06	12·32	12·54	12·79	13·00	13·22	13·42	34
35	9·76	10·14	10·53	10·86	11·17	11·50	11·76	12·05	12·30	12·56	12·79	13·04	13·25	13·48	13·68	35
36	9·95	10·34	10·73	11·07	11·38	11·72	11·99	12·28	12·54	12·80	13·04	13·29	13·50	13·74	13·94	36
37	10·14	10·54	10·93	11·28	11·59	11·94	12·22	12·51	12·78	13·04	13·29	13·54	13·76	14·00	14·20	37
38	10·33	10·74	11·13	11·49	11·81	12·16	12·45	12·74	13·02	13·28	13·54	13·79	14·02	14·26	14·46	38
39	10·52	10·94	11·34	11·70	12·03	12·38	12·68	12·97	13·26	13·52	13·79	14·04	14·28	14·52	14·73	39
40	10·71	11·14	11·54	11·91	12·26	12·60	12·91	13 21	13·50	13·77	14·04	14·29	14·54	14·78	15·00	40
41	10·88	11·31	11·72	12·10	12·45	12·80	13·11	13·42	13·71	13·99	14·26	14·51	14·77	15·01	15·24	41
42	11·05	11·49	11·90	12·29	12·64	13·00	13·31	13·63	13·92	14·21	14·48	14·74	15·00	15·24	15·48	42
43	11·22	11·67	12·08	12·48	12·83	13·20	13·51	13·84	14·13	14·43	14·70	14·97	15·23	15·47	15·72	43
44	11·39	11·85	12·26	12·67	13·03	13·40	13·72	14·05	14·34	14·65	14·92	15·20	15·46	15·70	15·96	44
45	11·56	12·03	12·44	12·86	13·23	13·60	13·93	14·26	14·56	14·87	15·14	15·43	15·69	15·94	16·20	45
46	11·73	12·21	12·63	13·05	13·43	13·80	14·14	14·47	14·78	15·09	15·37	15·66	15·92	16·18	16·44	46
47	11·90	12·39	12·82	13·24	13·63	14·00	14·35	14·68	15·00	15·31	15·60	15·89	16·15	16·42	16·68	47
48	12·07	12·57	13·01	13·43	13·83	14·20	14·56	14·89	15·22	15·53	15·83	16·12	16·39	16·66	16·92	48
49	12·25	12·75	13·20	13·62	14·03	14·40	14·77	15·10	15·44	15·75	16·06	16·35	16·63	16·90	17·16	49
50	12·43	12·93	13·39	13·82	14·23	14·61	14·98	15·32	15·66	15·98	16·29	16·58	16·87	17·14	17·41	50
51	12·59	13·09	13·56	13·99	14·41	14·79	15·17	15·51	15·86	16·18	16·50	16·79	17·08	17·36	17·63	51
52	12·75	13·25	13·73	14·17	14·59	14·98	15·36	15·70	16·06	16·38	16·71	17·00	17·29	17·58	17·85	52
53	12·91	13·41	13·90	14·35	14·77	15·17	15·55	15·90	16·26	16·58	16·92	17·21	17·51	17·80	18·07	53
54	13·07	13·58	14·07	14·53	14·95	15·36	15·74	16·10	16·47	16·78	17·13	17·42	17·73	18·02	18·29	54
55	13·23	13·75	14·24	14·71	15·13	15·55	15·93	16·30	16·67	16·99	17·34	17·63	17·95	18·24	18·51	55
56	13·39	13·92	14·41	14·89	15·31	15·74	16·12	16·50	16·87	17·20	17·55	17·85	18·17	18·46	18·74	56
57	13·55	14·09	14·58	15·07	15·50	15·93	16·31	16·70	17·07	17·41	17·76	18·07	18·39	18·68	18·97	57
58	13·71	14·26	14·76	15·25	15·69	16·12	16·51	16·90	17·27	17·62	17·97	18·29	18·61	18·90	19·20	58
59	13·87	14·43	14·94	15·43	15·88	16·31	16·71	17·10	17·48	17·83	18·18	18·51	18·83	19·13	19·43	59
60	14·04	14·60	15·12	15·61	16·07	16·50	16·91	17·30	17·68	18·04	18·39	18·73	19·05	19·36	19·66	60
61	14·19	14·75	15·28	15·77	16·24	16·67	17·09	17·48	17·87	18·23	18·58	18·93	19·25	19·57	19·87	61
62	14·34	14·90	15·44	15·94	16·41	16·85	17·27	17·66	18·06	18·42	18·78	19·13	19·45	19·78	20·08	62
63	14·49	15·05	15·60	16·11	16·58	17·03	17·45	17·85	18·25	18·61	18·98	19·33	19·65	19·99	20·29	63
64	14·64	15·21	15·76	16·28	16·75	17·21	17·63	18·04	18·44	18·80	19·18	19·54	19·85	20·20	20·50	64
65	14·79	15·37	15·92	16·45	16·92	17·39	17·81	18·23	18·63	19·00	19·38	19·74	20·06	20·41	20·71	65
66	14·94	15·53	16·08	16·62	17·09	17·57	17·99	18·42	18·82	19·20	19·58	19·94	20·27	20·62	20·92	66
67	15·09	15·69	16·25	16·79	17·26	17·75	18·17	18·61	19·01	19·40	19·78	20·15	20·48	20·83	21·13	67
68	15·24	15·85	16·42	16·96	17·44	17·93	18·35	18·80	19·20	19·60	19·98	20·35	20·69	21·04	21·34	68
69	15·40	16·01	16·59	17·13	17·62	18·11	18·54	18·99	19·40	19·80	20·18	20·55	20·90	21·25	21·56	69
70	15·56	16·18	16·76	17·30	17·81	18·29	18·74	19·18	19·60	20·00	20·38	20·76	21·11	21·46	21·79	70
71	15·70	16·33	16·91	17·46	17·97	18·46	18·91	19·35	19·78	20·18	20·57	20·95	21·31	21·66	22·00	71
72	15·84	16·48	17·06	17·62	18·13	18·63	19·08	19·52	19·96	20·36	20·76	21·14	21·51	21·86	22·20	72
73	15·98	16·63	17·21	17·78	18·29	18·80	19·25	19·69	20·14	20·54	20·95	21·33	21·70	22·06	22·40	73
74	16·12	16·78	17·36	17·94	18·45	18·97	19·42	19·87	20·32	20·72	21·14	21·52	21·90	22·26	22·60	74
75	16·26	16·93	17·51	18·10	18·61	19·14	19·59	20·05	20·50	20·91	21·33	21·71	22·10	22·46	22·81	75
76	16·40	17·08	17·67	18·26	18·78	19·31	19·77	20·23	20·68	21·10	21·52	21·90	22·29	22·65	23·01	76
77	16·55	17·23	17·83	18·42	18·95	19·48	19·95	20·41	20·86	21·29	21·71	22·09	22·49	22·85	23·21	77
78	16·69	17·38	17·99	18·58	19·12	19·65	20·13	20·59	21·04	21·48	21·90	22·28	22·68	23·05	23·42	78
79	16·84	17·53	18·15	18·74	19·29	19·82	20·31	20·77	21·23	21·67	22·09	22·48	22·88	23·25	23·62	79
80	17·00	17·68	18·31	18·91	19·46	19·99	20·49	20·96	21·42	21·86	22·28	22·69	23·07	23·45	23·82	80
81	17·14	17·82	18·46	19·06	19·62	20·15	20·65	21·13	21·59	22·04	22·46	22·87	23·26	23·65	24·02	81
82	17·28	17·96	18·61	19·21	19·78	20·31	20·81	21·30	21·76	22·22	22·64	23·05	23·45	23·85	24·21	82
83	17·42	18·10	18·76	19·36	19·94	20·47	20·97	21·47	21·93	22·40	22·82	23·23	23·64	24·04	24·41	83
84	17·56	18·24	18·91	19·51	20·10	20·64	21·14	21·64	22·10	22·58	23·00	23·41	23·83	24·23	24·60	84
85	17·70	18·38	19·06	19·67	20·26	20·80	21·31	21·81	22·28	22·76	23·18	23·60	24·02	24·42	24·79	85
86	17·84	18·53	19·21	19·83	20·42	20·96	21·48	21·98	22·46	22·94	23·36	23·79	24·21	24·61	24·99	86
87	17·98	18·68	19·36	19·99	20·58	21·12	21·65	22·15	22·64	23·12	23·54	23·98	24·40	24·80	25·18	87
88	18·12	18·83	19·51	20·15	20·74	21·28	21·82	22·32	22·82	23·30	23·72	24·17	24·59	24·99	25·37	88
89	18·26	18·98	19·66	20·31	20·90	21·45	21·99	22·50	23·00	23·47	23·91	24·36	24·78	25·18	25·57	89
90	18·40	19·13	19·81	20·45	21·06	21·62	22·16	22·68	23·18	23·64	24·10	24·54	24·96	25·37	25·76	90
91	18·53	19·26	19·95	20·59	21·21	21·77	22·33	22·85	23·35	23·81	24·27	24·71	25·14	25·56	25·95	91
92	18·66	19·40	20·09	20·74	21·36	21·92	22·50	23·02	23·52	23·98	24·44	24·89	25·32	25·75	26·14	92
93	18·79	19·54	20·23	20·89	21·51	22·08	22·66	23·19	23·69	24·15	24·61	25·07	25·50	25·94	26·33	93
94	18·92	19·68	20·37	21·04	21·66	22·24	22·82	23·36	23·86	24·32	24·78	25·25	25·68	26·13	26·52	94
95	19·05	19·82	20·51	21·19	21·81	22·40	22·98	23·53	24·03	24·49	24·95	25·43	25·86	26·31	26·71	95
96	19·18	19·96	20·65	21·34	21·96	22·56	23·14	23·69	24·20	24·66	25·12	25·61	26·04	26·49	26·90	96
97	19·32	20·10	20·80	21·49	21·11	22·72	23·30	23·85	24·37	24·83	25·30	25·79	26·22	26·67	27·09	97
98	19·46	20·24	20·95	21·64	21·27	22·88	23·46	24·01	24·54	25·00	25·48	25·97	26·40	26·85	27·28	98
99	19·60	20·38	21·10	21·79	21·43	23·04	23·62	24·17	24·70	25·18	25·66	26·15	26·58	27·03	27·46	99
100	19·74	20·52	21·25	21·94	22·59	23·20	23·78	24·33	24·86	25·36	25·85	26·33	26·78	27·21	27·64	100

LAND AND MARINE ENGINES. Content of the Feed Pump in Cubic Inches.

Length of Stroke in Feet.

Diameter of Cylinder in Inches.	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	Diameter of Cylinder in Inches.
21	29·57	37·08	44·50	51·91	59·33	66·75	74·17	81·58	89·00	96·41	103·83	111·25	128·66	126·08	133·50	21
22	32·60	40·83	49·00	57·16	65·33	73·50	81·67	89·83	98·00	106·16	114·33	122·50	150·66	138·83	147·00	22
23	35·60	44·58	53·50	62·41	71·33	80·25	89·17	98·08	107·00	115·91	124·83	133·75	172·67	151·58	160·50	23
24	38·67	48·33	58·00	67·66	77·33	87·00	96·67	106·33	116·00	125·66	135·33	145·00	184·67	164·33	174·00	24
25	41·67	52·08	62·50	72·92	83·33	93·75	104·17	114·58	125·00	135·42	145·83	156·25	166·67	177·08	187·50	25
26	45·33	56·66	68·00	79·33	90·66	102·20	113·33	124·66	136·00	147·33	158·66	170·00	181·33	192·66	204·00	26
27	48·99	61·24	73·50	85·74	97·99	110·65	122·49	134·74	147·00	159·24	171·49	183·75	195·99	208·24	220·50	27
28	52·66	65·82	79·00	92·15	105·32	119·10	131·65	144·82	158·00	171·15	184·32	197·50	210·65	223·82	237·00	28
29	56·32	70·40	84·50	98·56	112·65	127·55	140·81	154·90	169·00	183·06	197·15	211·25	225·31	239·40	253·50	29
30	60·00	75·00	90·00	105·00	120·00	135·00	150·00	165·00	180·00	195·00	210·00	225·00	240·00	255·00	270·00	30
31	64·33	80·41	96·50	112·58	128·66	144·75	160·83	176·91	193·00	209·08	225·16	241·24	257·33	273·41	289·50	31
32	68·66	85·82	103·00	120·16	137·32	154·50	171·66	188·82	206·00	223·16	240·32	257·48	274·66	291·82	309·00	32
33	72·99	91·23	109·50	127·74	145·98	164·25	182·49	200·73	219·00	237·24	255·47	273·72	291·99	310·23	328·50	33
34	77·33	96·64	116·00	135·32	154·64	174·00	193·32	212·64	232·00	251·32	270·63	289·96	309·32	328·64	348·00	34
35	81·67	102·09	122·51	142·93	163·34	183·75	204·17	224·59	245·00	265·42	285·83	306·24	326·65	347·06	367·50	35
36	86·67	108·33	130·00	147·67	173·33	195·00	216·67	238·33	260·00	281·66	303·33	324·99	346·65	368·31	390·00	36
37	91·67	114·57	137·49	152·41	183·32	206·25	229·17	252·07	275·00	297·90	320·83	343·74	366·65	389·56	412·50	37
38	96·68	120·81	144·98	157·15	193·31	217·50	241·68	265·81	290·00	314·14	338·33	362·49	386·66	410·81	435·00	38
39	101·68	127·06	152·47	161·89	203·30	228·75	254·18	279·55	305·00	330·38	355·83	381·24	406·66	432·06	457·50	39
40	106·68	133·33	160·00	166·66	213·33	240·00	266·68	293·33	320·00	346·66	373·33	400·00	426·66	453·33	480·00	40
41	112·34	140·41	168·50	176·57	224·66	252·75	280·84	308·91	337·00	365·08	393·16	421·25	449·32	477·41	505·50	41
42	118·00	147·49	177·00	186·48	235·99	265·50	295·00	324·49	354·00	383·49	412·99	442·50	471·98	501·49	531·00	42
43	123·66	154·57	185·50	196·39	247·32	278·50	309·16	340·07	371·00	401·90	432·82	463·75	494·64	525·57	556·50	43
44	129·32	161·65	194·00	206·30	258·65	291·25	323·32	355·65	388·00	420·31	452·65	485·00	517·30	549·65	582·00	44
45	135·00	168·75	202·50	236·25	270·00	303·75	337·50	371·25	405·00	438·75	472·50	506·25	540·00	573·75	607·50	45
46	141·33	176·66	212·00	247·33	282·66	318·00	353·33	388·66	424·00	459·33	494·66	530·00	565·33	600·66	636·00	46
47	147·66	184·57	221·50	258·41	295·32	332·25	369·16	406·07	443·00	479·91	516·82	553·75	590·66	627·57	664·50	47
48	153·99	192·48	231·00	269·49	307·98	346·50	384·99	423·48	462·00	500·49	538·98	577·50	615·99	654·48	693·00	48
49	160·33	200·39	240·50	270·57	320·64	360·75	400·82	440·89	481·00	521·07	561·14	601·25	641·32	681·39	721·50	49
50	166·67	208·33	250·00	291·67	333·33	375·00	416·67	458·33	500·00	541·67	583·33	625·00	666·67	708·33	750·00	50
51	173·60	217·08	250·50	303·92	347·33	390·75	434·17	477·58	521·00	564·42	607·83	651·25	694·67	738·08	781·50	51
52	180·61	225·83	271·00	316·17	361·33	406·50	451·67	496·83	542·00	587·17	632·33	677·50	722·67	767·83	813·00	52
53	187·64	234·58	281·50	328·42	375·34	422·25	469·18	516·08	563·00	609·92	656·83	703·75	750·67	797·58	844·50	53
54	194·66	243·33	292·00	340·67	389·34	438·00	486·68	535·33	584·00	632·67	681·34	730·00	778·68	827·33	876·00	54
55	201·67	252·09	302·51	352·93	403·35	453·77	504·19	554·60	605·01	655·42	705·84	756·26	806·68	857·09	907·50	55
56	209·33	261·67	314·00	366·34	418·68	471·01	520·35	575·68	628·01	680·33	732·67	785·00	837·34	889·67	942·00	56
57	216·99	271·25	325·49	379·75	434·01	488·25	539·51	596·76	651·01	705·24	759·50	813·74	868·00	922·25	976·50	57
58	224·66	280·53	336·98	393·16	449·34	505·49	558·67	617·84	674·01	730·15	786·35	842·48	898·66	954·83	1011·00	58
59	232·32	290·11	348·47	406·57	464·67	522·73	577·83	638·92	697·01	755·06	813·18	871·22	929·32	987·41	1045·50	59
60	240·00	390·00	360·00	420·00	480·00	540·00	600·00	660·00	720·00	780·00	840·00	900·00	960·00	1020·00	1080·00	60
61	248·33	310·41	372·50	434·58	496·66	558·75	620·83	682·91	745·00	807·08	869·17	931·25	993·34	1055.40	1117·50	61
62	256·66	320·82	385·00	449·16	513·32	577·50	641·66	705·82	770·00	834·16	898·34	962·50	1026·68	1090·80	1155·00	62
63	264·99	331·23	397·50	463·74	529·96	596·25	662·49	728·73	795·00	861·24	917·51	993·75	1060·02	1126·20	1192·50	63
64	273·32	341·64	410·00	478·32	546·62	615·00	683·32	751·64	820·00	888·32	946·68	1025·00	1093·36	1161·60	1230·00	64
65	281·67	352·09	422·51	492·93	563·34	633·76	704·18	774·59	845·01	915·43	985·85	1056·27	1126·70	1197·04	1267·50	65
66	290·33	362·97	435·62	508·26	580·66	653·30	725·94	798·58	871·24	943·88	1016·52	1089·16	1161·32	1233·96	1306·86	66
67	299·13	374·02	448·92	523·81	598·26	673·38	748·27	823·16	897·84	972·74	1047·64	1122·54	1196·52	1271·42	1346·76	67
68	308·06	385·24	462·42	539·60	616·12	693·63	770·81	847·99	924·84	1002·02	1079·20	1156·38	1232·24	1309·42	1387·26	68
69	317·12	346·62	476·12	505·62	634·24	714·18	743·68	873·18	952·24	1031·30	1110·36	1189·42	1268·48	1348·42	1428·36	69
70	326·67	408·33	489·99	571·67	653·33	734·99	816·66	898·33	979·99	1061·66	1143·33	1224·99	1306·66	1388·33	1470·00	70
71	336·07	420·08	504·09	588·11	672·14	756·13	840·15	924·17	1008·18	1092·20	1176·22	1260·24	1344·28	1428·28	1512·27	71
72	345·60	432·08	518·49	604·84	691·20	777·73	864·15	950·57	1036·98	1123·35	1209·72	1296·09	1382·40	1468·93	1555·47	72
73	355·26	444·12	532·99	621·75	710·52	799·48	888·31	977·14	1065·98	1154·74	1243·50	1332·26	1421·04	1510·00	1598·97	73
74	365·06	456·37	547·69	638·90	730·12	821·53	912·81	1004·09	1095·38	1186·59	1277·80	1369·01	1460·24	1551·65	1643·07	74
75	375·00	468·75	562·50	656·25	750·00	843·75	937·50	1031·25	1125·00	1218·75	1312·50	1406·25	1500·00	1593·75	1687·50	75
76	385·06	481·33	577·60	673·86	770·12	866·40	962·68	1058·96	1155·20	1251·46	1347·72	1443·98	1540·24	1636·52	1732·80	76
77	395·25	494·07	592·90	691·70	790·50	889·35	988·17	1086·99	1185·80	1284·60	1383·40	1482·20	1581·00	1679·85	1778·70	77
78	405·58	506·99	608·40	709·78	811·16	912·60	1014·00	1115·40	1216·80	1318·20	1419·60	1521·00	1622·32	1723·76	1825·20	78
79	416·04	520·07	624·10	728·09	832·08	936·15	1040·17	1144·19	1248·20	1352·19	1456·18	1560·17	1664·16	1768·23	1872·30	79
80	426·72	533·33	640·00	666·66	853·33	960·00	1066·72	1173·33	1280·00	1386·66	1493·33	1600·00	1706·66	1813·33	1920·00	80
81	437·44	546·77	656·10	765·42	874·88	984·15	1093·55	1202·87	1312·20	1421·54	1530·84	1640·16	1749·76	1850·08	1968·30	81
82	448·29	560·35	672·40	784·40	896·58	1008·60	1120·71	1232·75	1344·80	1456·80	1568·81	1680·98	1793·16	1905·18	2017·20	82
83	459·28	574·10	688·90	803·42	918·56	1033·35	1148·20	1263·00	1377·80	1492·52	1607·25	1722·18	1837·12	1951·93	2066·70	83
84	470·40	588·01	705·60	823·07	940·80	1058·40	1176·02	1293·61	1411·20	1528·67	1646·15	1763·87	1881·60	1999·20	2116·80	84
85	481·67	602·08	722·50	842·91	963·33	1083·74	1204·15	1324·56	1445·00	1565·41	1685·83	1706·24	1926·67	2047·08	2167·50	85
86	493·05	616·31	739·60	862·83	986·10	1109·40	1232·63	1355·91	1479·20	1602·43	1725·66	1848·93	1972·20	2095·50	2218·80	86
87	504·57	630·72	756·90	882·97	1009·14	1135·35	1261·45	1387·62	1513·80	1639·87	1765·95	1892·11	2018·28	2144·49	2270·70	87
88	516·22	645·30	774·40	903·35	1032·44	1161·60	1290 60	1419·70	1548·80	1677·75	1806·71	1935·79	2064·88	2194·04	2323·20	88
89	528·00	660·04	792·10	923·96	1056·00	1188·15	1320·09	1452·14	1584·20	1716·06	1847·93	1979·96	2112·00	2244·15	2376·30	89
90	540·00	675·00	810·00	945·00	1080·00	1215·00	1350·00	1485·00	1620·00	1755·00	1890·00	2025·00	2160·00	2295·00	2430·00	90
91	552·05	690·07	828·10	966·07	1104·10	1242·15	1380·15	1518·17	1656·20	1794·17	1932·15	2070·17	2208·20	2346·25	2484·30	91
92	564·23	705·32	846·40	987·38	1128·46	1269·60	1410·64	1551·73	1692·80	1833·78	1974·77	2115·84	2256·92	2398·06	2539·20	92
93	576·55	720·73	864·90	1008·93	1153·10	1297·35	1441·46	1585·63	1729·80	1873·83	2017·86	2162·03	2306·20	2450·45	2594·70	93
94	588·97	736·30	883·60	1030·70	1177 94	1325·40	1472·61	1619·90	1767·20	1914·30	2061·41	2208·64	2355·88	2503·34	2650·80	94
95	601·66	752·07	902·49	1052·90	1203·33	1353·74	1504·16	1654·58	1805·00	1955·41	2105·82	2256·24	2406·67	2557·08	2707·50	95
96	614·26	767·99	921·59	1075·15	1228·52	1382·38	1535·98	1689·58	1843·18	1996·74	2150·30	2303·67	2457·04	2610·90	2764·77	96
97	626·99	784·07	940·89	1097·62	1253·98	1411·33	1568·14	1724·96	1881·78	2038·51	2195·25	2351·60	2507·96	2665·31	2822·67	97
98	639·85	800·31	960·39	1120·33	1279·70	1440·58	1600·63	1760·70	1920·78	2080·72	2240·66	2400·03	2559·40	2720 28	2881·17	98
99	652·85	818·72	980·09	1143·27	1305·70	1470·13	1637·45	1798·81	1960·18	2123·36	2286·54	2448·97	2611·40	2775·83	2940·27	99
100	666·67	833·34	1000·00	1166·67	1333·33	1500·00	1666·66	1833·33	2000·00	2166·66	2333·33	2500·00	2666·66	2833·33	3000·00	100

Land Engines. Content of Cold Water Pump in Cubic Feet.

Diameter of Cylinder in Inches.	Length of Stroke in Feet.															Diameter of Cylinder in Inches.
	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	
20	·18	·23	·27	·32	·36	·41	·45	·50	·54	·59	·63	·68	·72	·77	·82	20
21	·20	·25	·30	·35	·40	·45	·50	·55	·60	·65	·70	·75	·80	·85	·91	21
22	·22	·27	·33	·38	·44	·49	·55	·60	·66	·71	·77	·82	·88	·93	1·00	22
23	·24	·29	·36	·42	·48	·54	·60	·66	·72	·78	·84	·90	·96	1·02	1·09	23
24	·26	·32	·39	·46	·52	·59	·65	·72	·78	·85	·91	·98	1·04	1·11	1·18	24
25	·28	·35	·42	·50	·57	·64	·71	·78	·85	·92	·99	1·06	1·13	1·20	1·28	25
26	·30	·38	·45	·54	·62	·69	·77	·84	·92	1·00	1·07	1·15	1·23	1·30	1·39	26
27	·32	·41	·49	·58	·67	·74	·83	·91	·99	1·08	1·16	1·24	1·33	1·41	1·50	27
28	·35	·44	·53	·62	·72	·80	·90	·98	1·07	1·16	1·25	1·33	1·43	1·52	1·61	28
29	·38	·47	·57	·67	·77	·86	·97	1·05	1·15	1·24	1·34	1·43	1·53	1·63	1·73	29
30	·41	·51	·61	·72	·82	·92	1·02	1·12	1·23	1·33	1·43	1·53	1·64	1·74	1·85	30
31	·44	·54	·65	·77	·87	·98	1·09	1·20	1·31	1·42	1·53	1·64	1·75	1·86	1·98	31
32	·47	·57	·69	·82	·93	1·04	1·16	1·28	1·40	1·51	1·63	1·75	1·86	1·98	2·11	32
33	·50	·61	·73	·87	·99	1·11	1·23	1·36	1·49	1·60	1·73	1·86	1·98	2·10	2·24	33
34	·53	·65	·78	·92	1·05	1·18	1·31	1·44	1·58	1·70	1·84	1·97	2·10	2·23	2·37	34
35	·56	·69	·83	·97	1·11	1·25	1·39	1·53	1·67	1·80	1·94	2·08	2·22	2·36	2·50	35
36	·59	·73	·88	1·03	1·17	1·32	1·47	1·62	1·77	1·91	2·06	2·20	2·35	2·50	2·65	36
37	·62	·77	·93	1·09	1·24	1·39	1·55	1·71	1·87	2·02	2·18	2·33	2·48	2·64	2·80	37
38	·66	·81	·98	1·15	1·31	1·47	1·63	1·80	1·97	2·13	2·30	2·46	2·62	2·78	2·95	38
39	.70	·86	1·03	1·21	1·38	1·55	1·72	1·90	2·07	2·24	2·42	2·59	2·76	2·93	3·11	39
40	·73	·91	1·09	1·27	1·45	1·63	1·81	2·00	2·18	2·36	2·54	2·72	2·90	3·09	3·27	40
41	·76	·95	1·14	1·33	1·52	1·71	1·90	2·10	2·29	2·48	2·67	2·86	3·05	3·25	3·44	41
42	·80	1·00	1·20	1·39	1·60	1·80	2·00	2·20	2·40	2·60	2·80	3·00	3·20	3·41	3·61	42
43	·84	1·05	1·26	1·46	1·68	1·89	2·10	2·31	2·52	2·73	2·94	3·15	3·36	3·57	3·78	43
44	·88	1·10	1·32	1·53	1·76	1·98	2·20	2·42	2·64	2·86	3·08	3·30	3·52	3·74	3·96	44
45	·92	1·15	1·38	1·61	1·84	2·07	2·30	2·53	2·76	2·99	3·22	3·45	3·68	3·91	4·14	45
46	·96	1·20	1·44	1·68	1·92	2·16	2·40	2·64	2·89	3·13	3·37	3·61	3·85	4·09	4·33	46
47	1·00	1·25	1·50	1·75	2·00	2·25	2·51	2·76	3·02	3·27	3·52	3·77	4·02	4·27	4·52	47
48	1·04	1·30	1·56	1·83	2·09	2·35	2·62	2·88	3·15	3·41	3·67	3·93	4·19	4·45	4·71	48
49	1·09	1·36	1·63	1·91	2·18	2·45	2·73	3·00	3·28	3·55	3·82	4·09	4·36	4·63	4·90	49
50	1·14	1·42	1·70	1·99	2·27	2·55	2·84	3·12	3·41	3·69	3·97	4·26	4·54	4·82	5·11	50
51	1·18	1·47	1·77	2·07	2·38	2·65	2·95	3·25	3·55	3·84	4·13	4·43	4·73	5·02	5·32	51
52	1·22	1·53	1·84	2·15	2·49	2·76	3·07	3·38	3·69	3·99	4·30	4·61	4·92	5·22	5·53	52
53	1·27	1·59	1·91	2·23	2·61	2·87	3·19	3·51	3·83	4·15	4·47	4·79	5·11	5·43	5·75	53
54	1·32	1·65	1·98	2·31	2·73	2·98	3·31	3·64	3·97	4·31	4·64	4·97	5·30	5·64	5·97	54
55	1·37	1·71	2·05	2·40	2·74	3·09	3·43	3·77	4·12	4·46	4·81	5·15	5·50	5·84	6·19	55
56	1·42	1·77	2·13	2·49	2·84	3·21	3·56	3·91	4·27	4·63	4·99	5·34	5·71	6·06	6·42	56
57	1·47	1·84	2·21	2·58	2·95	3·33	3·69	4·05	4·42	4·80	5·17	5·54	5·92	6·28	6·65	57
58	1·52	1·91	2·29	2·67	3·06	3·45	3·82	4·20	4·58	4·97	5·35	5·74	6·13	6·50	6·89	58
59	1·58	1·98	2·37	2·77	3·17	3·57	3·95	4·35	4·74	5·14	5·54	5·94	6·34	6·73	7·12	59
60	1·64	2·05	2·46	2·87	3·28	3·69	4·09	4·50	4·91	5·32	5·73	6·14	6·55	6·96	7·36	60
61	1·69	2·12	2·54	2·96	3·39	3·81	4·23	4·65	5·08	5·50	5·92	6·35	6·77	7·20	7·61	61
62	1·74	2·19	2·62	3·06	3·50	3·93	4·37	4·80	5·25	5·68	6·12	6·56	6·99	7·44	7·87	62
63	1·80	2·26	2·70	3·16	3·61	4·05	4·51	4·95	5·42	5·86	6·32	6·77	7·22	7·68	8·13	63
64	1·86	2·33	2·79	3·26	3·72	4·18	4·66	5·11	5·59	6·05	6·52	6·98	7·45	7·92	8·39	64
65	1·92	2·40	2·88	3·36	3·84	4·32	4·80	5·28	5·76	6·24	6·72	7·20	7·68	8·16	8·64	65
66	1·98	2·47	2·97	3·46	3·96	4·45	4·95	5·44	5·94	6·43	6·93	7·42	7·92	8·41	8·91	66
67	2·04	2·54	3·06	3·56	4·08	4·58	5·10	5·60	6·12	6·62	7·14	7·65	8·16	8·67	9·18	67
68	2·10	2·62	3·15	3·67	4·20	4·72	5·25	5·77	6·30	6·82	7·35	7·88	8·40	8·93	9·46	68
69	2·16	2·70	3·24	3·78	4·32	4·86	5·40	5·94	6·48	7·02	7·56	8·11	8·64	9·19	9·74	69
70	2·23	2·78	3·34	3·89	4·45	5·00	5·56	6·11	6·67	7·22	7·78	8·34	8·89	9·45	10·02	70
71	2·29	2·86	3·44	4·00	4·58	5·15	5·72	6·29	6·87	7·44	8·01	8·59	9·16	9·73	10·31	71
72	2·35	2·94	3·54	4·12	4·71	5·30	5·89	6·47	7·07	7·66	8·24	8·84	9·43	10·01	10·61	72
73	2·42	3·02	3·64	4·24	4·84	5·45	6·06	6·66	7·27	7·88	8·48	9·10	9·70	10·30	10·91	73
74	2·49	3·11	3·74	4·36	4·98	5·60	6·23	6·85	7·47	8·10	8·72	9·36	9·97	10·59	11·21	74
75	2·56	3·20	3·84	4·48	5·12	5·76	6·40	7·04	7·68	8·32	8·96	9·60	10·24	10·88	11·51	75
76	2·63	3·28	3·94	4·60	5·25	5·91	6·57	7·23	7·88	8·54	9·20	9·85	10·51	11·17	11·82	76
77	2·70	3·36	4·04	4·72	5·39	6·06	6·74	7·42	8·09	8·76	9·44	10·11	10·78	11·46	12·13	77
78	2·77	3·45	4·14	4·84	5·53	6·22	6·91	7·61	8·30	8·98	9·68	10·37	11·06	11·75	12·45	78
79	2·84	3·54	4·25	4·96	5·67	6·38	7·08	7·80	8·51	9·21	9·92	10·63	11·34	12·04	12·76	79
80	2·91	3·63	4·36	5·09	5·81	6·54	7·26	7·99	8·72	9·44	10·17	10·89	11·62	12·35	13·09	80
81	2·98	3·72	4·47	5·22	5·96	6·70	7·44	8·19	8·94	9·68	10·43	11·17	11·92	12·66	13·42	81
82	3·05	3·81	4·58	5·35	6·11	6·87	7·63	8·39	9·16	9·92	10·69	11·45	12·22	12·98	13·76	82
83	3·12	3·90	4·69	5·48	6·26	7·04	7·82	8·60	9·38	10·16	10·95	11·73	12·52	13·30	14·10	83
84	3·20	4·00	4·80	5·61	6·41	7·21	8·01	8·81	9·61	10·41	11·21	12·01	12·82	13·62	14·44	84
85	3·28	4·10	4·92	5·74	6·56	7·38	8·20	9·02	9·84	10·66	11·48	12·30	13·12	13·94	14·78	85
86	3·36	4·20	5·04	5·88	6·72	7·56	8·40	9·24	10·08	10·92	11·76	12·60	13·44	14·28	15·13	86
87	3·44	4·30	5·16	6·02	6·88	7·74	8·60	9·46	10·32	11·18	12·04	12·90	13·76	14·62	15·49	87
88	3·52	4·40	5·28	6·16	7·04	7·92	8·80	9·68	10·56	11·44	12·32	13·20	14·08	14·96	15·85	88
89	3·60	4·50	5·40	6·30	7·20	8·10	9·00	9·90	10·80	11·70	12·60	13·50	14·40	15·30	16·21	89
90	3·68	4·60	5·52	6·44	7·36	8·28	9·20	10·12	11·04	11·96	12·88	13·80	14·72	15·64	16·57	90
91	3·76	4·70	5·64	6·58	7·53	8·47	9·41	10·35	11·29	12·23	13·18	14·12	15·06	16·00	16·94	91
92	3·84	4·80	5·76	6·73	7·70	8·66	9·62	10·58	11·54	12·51	13·48	14·44	15·40	16·36	17·32	92
93	3·92	4·91	5·89	6·88	7·87	8·85	9·83	10·82	11·80	12·79	13·78	14·76	15·74	16·72	17·70	93
94	4·01	5·02	6·02	7·03	8·04	9·04	10·05	11·06	12·06	13·07	14·08	15·08	16·08	17·08	18·08	94
95	4·10	5·13	6·15	7·18	8·21	9·24	10·27	11·30	12·32	13·35	14·38	15·41	16·43	17·45	18·46	95
96	4·19	5·24	6·28	7·33	8·38	9·43	10·48	11·53	12·58	13·63	14·68	15·73	16·77	17·82	18·85	96
97	4·28	5·35	6·41	7·48	8·55	9·62	10·70	11·77	12·84	13·91	14·98	16·05	17·12	18·19	19·25	97
98	4·37	5·46	6·54	7·63	8·73	9·82	10·92	12·01	13·10	14·19	15·28	16·37	17·47	18·56	19·65	98
99	4·46	5·57	6·68	7·79	8·91	10·02	11·14	12·25	13·36	14·47	15·59	16·70	17·82	18·93	20·05	99
100	4·55	5·68	6·82	7·95	9·09	10·22	11·36	12·49	13·63	14·76	15·90	17·03	18·17	19·30	20·45	100

Diameter of Cylinder in Inches.	Land Engines. Thickness of large Eye of Crank for Fly-Wheel Shaft, when of Cast Iron, in Inches.														Diameter of Cylinder in Inches.
	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	
20	2·39	2·52	2·65	2·76	2·87	2·97	3·07	3·15	3·25	3·33	3·42	3·50	3·57	3·64	3·70	20
21	2·48	2·61	2·75	2·86	2·98	3·08	3·18	3·26	3·36	3·44	3·53	3·61	3·69	3·77	3·85	21
22	2·57	2·70	2·85	2·96	3·09	3·19	3·29	3·37	3·47	3·55	3·64	3·72	3·81	3·90	4·00	22
23	2·66	2·79	2·95	3·06	3·20	3·30	3·40	3·48	3·58	3·66	3·75	3·83	3·93	4·03	4·15	23
24	2·74	2·88	3·04	3·16	3·31	3·41	3·51	3·59	3·69	3·77	3·85	3·94	4·05	4·16	4·30	24
25	2·82	2·97	3·13	3·26	3·42	3·52	3·62	3·70	3·80	3·88	3·95	4·05	4·17	4·29	4·45	25
26	2·90	3·06	3·22	3·36	3·52	3·62	3·72	3·81	3·91	3·98	4·05	4·16	4·29	4·42	4·59	26
27	2·98	3·15	3·31	3·46	3·62	3·72	3·82	3·91	4·01	4·08	4·15	4·27	4·41	4·55	4·73	27
28	3·06	3·24	3·40	3·56	3·72	3·82	3·92	4·01	4·11	4·18	4·25	4·38	4·53	4·68	4·87	28
29	3·14	3·32	3·49	3·66	3·82	3·92	4·02	4·11	4·21	4·28	4·35	4·48	4·64	4·81	5·01	29
30	3·22	3·40	3·58	3·75	3·92	4·02	4·12	4·21	4·31	4·38	4·45	4·58	4·75	4·93	5·15	30
31	3·31	3·49	3·67	3·84	4·01	4·11	4·22	4·30	4·41	4·48	4·56	4·68	4·84	5·01	5·22	31
32	3·40	3·58	3·76	3·93	4·10	4·20	4·32	4·40	4·50	4·58	4·66	4·78	4·93	5·09	5·29	32
33	3·49	3·67	3·85	4·02	4·19	4·29	4·41	4·50	4·60	4·68	4·76	4·88	5·02	5·17	5·36	33
34	3·58	3·76	3·94	4·11	4·28	4·38	4·50	4·60	4·70	4·78	4·86	4·97	5·11	5·25	5·43	34
35	3·67	3·85	4·03	4·20	4·37	4·47	4·59	4·69	4·80	4·88	4·96	5·07	5·20	5·33	5·50	35
36	3·76	3·94	4·12	4·29	4·46	4·56	4·68	4·78	4·90	4·98	5·06	5·16	5·29	5·41	5·56	36
37	3·85	4·03	4·20	4·37	4·55	4·65	4·77	4·87	4·99	5·08	5·16	5·26	5·38	5·49	5·62	37
38	3·94	4·11	4·28	4·45	4·63	4·74	4·86	4·97	5·09	5·18	5·26	5·35	5·47	5·57	5·68	38
39	4·02	4·19	4·36	4·53	4·71	4·83	4·95	5·07	5·19	5·28	5·36	5·44	5·56	5·65	5·75	39
40	4·10	4·27	4·44	4·61	4·79	4·91	5·04	5·17	5·29	5·38	5·46	5·54	5·64	5·73	5·81	40
41	4·24	4·39	4·54	4·71	4·89	5·00	5·14	5·26	5·39	5·47	5·57	5·65	5·75	5·84	5·93	41
42	4·38	4·51	4·65	4·81	4·99	5·09	5·23	5·36	5·49	5·57	5·68	5·76	5·86	5·95	6·05	42
43	4·52	4·63	4·76	4·91	5·08	5·19	5·33	5·45	5·59	5·67	5·79	5·87	5·97	6·06	6·17	43
44	4·66	4·75	4·87	5·01	5·17	5·28	5·42	5·54	5·69	5·77	5·90	5·98	6·08	6·17	6·28	44
45	4·80	4·87	4·98	5·12	5·26	5·37	5·51	5·63	5·78	5·87	6·00	6·09	6·19	6·28	6·39	45
46	4·94	4·99	5·09	5·22	5·36	5·47	5·60	5·72	5·87	5·97	6·10	6·20	6·30	6·39	6·50	46
47	5·08	5·11	5·20	5·32	5·45	5·56	5·70	5·82	5·96	6·07	6·20	6·31	6·41	6·50	6·61	47
48	5·22	5 23	5·31	5·42	5·54	5·66	5·79	5·91	6·06	6·17	6·30	6·41	6·52	6·61	6·72	48
49	5·36	5·36	5·42	5·53	5·64	5·75	5·88	6·00	6·15	6·27	6·40	6·51	6·63	6·72	6·83	49
50	5·50	5·49	5·53	5·63	5·73	5·85	5·98	6·10	6·24	6·37	6·50	6·61	6·73	6·83	6·94	50
51	5·63	5·60	5·64	5·73	5·83	5·95	6·07	6·19	6·34	6·46	6·59	6·70	6·83	6·93	7·04	51
52	5·75	5·71	5·74	5·84	5·93	6·04	6·17	6·28	6·43	6·56	6·68	6·80	6·93	7·03	7·14	52
53	5·87	5·82	5·85	5·94	6·03	6·14	6·26	6·38	6·52	6·65	6·77	6·90	7·03	7·13	7·24	53
54	5·99	5·93	5·96	6·04	6·13	6·24	6·36	6·47	6·61	6·74	6·87	6·99	7·13	7·23	7·34	54
55	6·11	6·04	6·06	6·15	6·23	6·33	6·45	6·56	6·70	6·83	6·96	7·08	7·23	7·33	7·44	55
56	6·23	6·15	6·17	6·25	6·33	6·43	6·55	6·66	6·80	6·92	7·06	7·17	7·33	7·43	7·54	56
57	6·35	6·26	6·28	6·35	6·43	6·53	6·64	6·76	6·89	7·01	7·15	7·26	7·42	7·53	7·64	57
58	6·47	6·37	6·39	6·46	6·52	6·62	6·74	6·85	6·98	7·10	7·24	7·35	7·51	7·62	7·74	58
59	6·59	6·47	6·50	6·56	6·62	6·72	6·83	6·95	7·08	7·20	7·34	7·44	7·60	7·71	7·83	59
60	6·71	6·57	6·61	6·66	6·72	6·82	6·93	7·04	7·17	7·29	7·43	7·53	7·69	7·80	7·92	60
61	6·84	6·70	6·72	6·75	6·82	6·92	7·03	7·14	7·27	7·39	7·53	7·63	7·79	7·90	8·02	61
62	6·97	6·83	6·83	6·84	6·93	7·02	7·13	7·24	7·37	7·49	7·62	7·72	7·89	8·00	8·12	62
63	7·10	6·96	6·94	6·93	7·03	7·12	7·23	7·34	7·47	7·58	7·72	7·81	7·98	8·10	8·22	63
64	7·23	7·09	7·05	7·02	7·13	7·22	7·33	7·44	7·56	7·67	7·82	7·91	8·07	8·20	8·31	64
65	7·36	7·22	7·16	7·11	7·23	7·31	7·43	7·54	7·66	7·77	7·91	8·00	8·16	8·29	8·41	65
66	7·49	7·35	7·27	7·20	7·33	7·41	7·53	7·63	7·76	7·87	8·00	8·10	8·25	8·38	8·51	66
67	7·62	7·48	7·38	7·29	7·43	7·51	7·63	7·73	7·85	7·96	8·10	8·19	8·35	8·47	8·60	67
68	7·74	7·60	7·49	7·38	7·53	7·61	7·72	7·83	7·94	8·06	8·19	8·29	8·44	8·57	8·70	68
69	7·86	7·72	7·59	7·47	7·63	7·71	7·81	7·92	8·03	8·16	8·28	8·38	8·53	8·66	8·80	69
70	7·98	7·84	7·69	7·56	7·73	7·81	7·90	8·01	8·12	8·25	8·37	8·48	8·62	8·75	8·89	70
71	8·11	7·96	7·80	7·66	7·83	7·91	8·00	8·11	8·22	8·35	8·46	8·58	8·72	8·85	8·99	71
72	8·24	8·08	7·91	7·76	7·94	8·02	8·10	8·21	8·32	8·44	8·56	8·68	8·81	8·94	9·08	72
73	8·37	8·20	8·02	7·86	8·04	8·12	8·20	8·31	8·41	8·54	8·65	8·77	8·91	9·04	9·18	73
74	8·50	8·32	8·13	7·96	8·14	8·22	8·31	8·41	8·51	8·64	8·75	8·87	9·00	9·13	9·27	74
75	8·63	8·44	8·25	8·07	8·25	8·32	8·41	8·51	8·61	8·73	8·85	8·97	9·10	9·23	9·37	75
76	8·76	8·57	8 37	8·18	8·35	8·42	8·51	8·61	8·70	8·83	8·94	9·06	9·20	9·32	9·46	76
77	8·90	8·70	8·49	8·29	8·45	8·52	8·61	8·70	8·80	8·93	9·04	9·16	9·29	9·42	9·55	77
78	9·04	8·83	8·61	8·40	8·56	8·63	8·72	8·80	8·90	9·02	9·13	9·26	9·39	9·51	9·64	78
79	9·18	8·96	8·73	8·51	8·66	8·73	8·82	8·90	9·00	9·12	9·23	9·35	9·48	9·61	9·74	79
80	9·32	9·09	8·85	8·62	8·76	8·83	8·92	9·00	9·10	9·21	9·33	9·45	9·58	9·70	9·83	80
81	9·46	9·22	8·97	8·75	8·87	8·94	9·02	9·09	9·19	9·31	9·43	9·54	9·68	9·80	9·93	81
82	9·60	9·35	9·09	8·88	8·98	9·04	9·12	9·19	9·28	9·41	9·53	9·64	9·77	9·89	10·02	82
83	9·74	9·48	9·21	9·01	9·09	9·14	9·22	9·28	9·37	9·51	9·63	9·73	9·86	9·98	10·12	83
84	9·88	9·61	9·33	9·14	9·20	9·25	9·31	9·38	9·46	9·60	9·73	9·83	9·96	10·08	10·21	84
85	10·02	9·74	9·45	9·27	9·31	9·35	9·41	9·47	9·55	9·69	9·83	9·92	10·01	10·12	10·25	85
86	10·16	9·87	9·57	9·40	9·42	9·46	9·51	9·57	9·64	9·78	9·92	10·01	10·05	10·17	10·30	86
87	10·30	10·00	9·69	9·53	9·53	9·56	9·61	9·66	9·73	9·87	10·01	10·11	10·14	10·26	10·40	87
88	10·44	10·13	9·81	9·67	9·64	9·67	9·71	9·76	9·82	9·96	10·10	10·20	10·23	10·36	10·49	88
89	10·59	10·26	9·93	9·81	9·75	9·77	9·81	9·85	9·91	10·05	10·19	10·30	10·32	10·45	10·58	89
90	10·74	10·39	10·05	9·95	9·87	9·88	9·91	9·95	10·00	10·14	10·28	10·39	10·51	10·64	10·77	90
91	10·88	10·52	10·17	10·07	9·98	9·99	10·02	10·06	10·11	10·24	10·38	10·49	10·61	10·74	10·87	91
92	11·02	10·65	10·29	10·19	10·09	10·10	10·12	10·16	10·21	10·34	10·47	10·58	10·70	10·83	10·96	92
93	11·16	10·78	10·42	10·31	10·20	10·21	10·23	10·27	10·32	10·45	10·57	10·68	10·80	10·93	11·05	93
94	11·31	10·92	10·55	10·43	10·31	10·32	10·33	10·38	10·42	10·55	10·67	10·77	10·89	11·02	11·15	94
95	11·46	11·06	10·68	10·55	10·42	10·43	10·44	10·48	10·53	10·65	10·77	10·87	10·99	11·12	11·24	95
96	11·61	11·20	10·81	10·67	10·53	10·54	10·54	10·59	10·64	10·75	10·87	10·96	11·08	11·21	11·33	96
97	11·76	11·34	10·94	10·79	10·64	10·65	10·65	10·69	10·74	10·85	10·96	11·06	11·18	11·31	11·43	97
98	11·91	11·48	11·07	10·91	10·76	10·76	10·75	10·80	10·85	10·96	11·06	11·16	11·28	11·40	11·52	98
99	12·06	11·62	11·20	11·03	10·88	10·87	10·86	10·91	10·96	11·06	11·16	11·25	11·37	11·49	11·61	99
100	12·21	11·76	11·33	11·16	11·00	10·98	10·96	11·02	11·07	11·16	11·26	11 35	11·47	11·58	11·70	100

{ Length of Stroke in Feet.

Dimensions of Parts of Land Engines.

Diameter of Cylinder in Inches.	LAND ENGINES. Breadth of Crank at Centre of Fly-Wheel Shaft, when of Cast Iron, in Inches.															Diameter of Cylinder in Inches.
	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	Length of Stroke in Feet.
20	6·60	6·81	7·02	7·55	8·07	8·40	8·72	8·99	9·25	9·49	9·72	9·94	10·15	10·36	10·55	20
21	6·88	7·10	7·31	7·83	8·34	8·68	9·01	9·28	9·55	9·79	10·03	10·26	10·47	10·69	10·89	21
22	7·15	7·39	7·60	8·11	8·61	8·96	9·30	9·57	9·85	10·09	10·33	10·58	10·79	11·02	11·23	22
23	7·43	7·68	7·89	8·39	8·88	9·24	9·59	9·86	10·14	10·38	10·64	10·89	11·11	11·35	11·56	23
24	7·70	7·96	8·18	8·67	9·15	9·52	9·87	10·15	10·43	10·68	10·94	11·20	11·43	11·68	11·89	24
25	7·98	8·24	8·47	8·95	9·42	9·80	10·15	10·44	10·72	10·98	11·25	11·51	11·75	12·01	12·22	25
26	8·26	8·52	8·76	9·23	9·69	10·07	10·43	10·73	11·01	11·28	11·55	11·82	12·07	12·33	12·55	26
27	8·53	8·80	9·05	9·51	9·96	10·34	10·71	11·02	11·30	11·58	11·86	12·13	12·39	12·65	12·88	27
28	8·81	9·08	9·34	9·78	10·23	10·61	10·99	11·30	11·59	11·87	12·16	12·44	12·71	12·97	13·21	28
29	9·09	9·36	9·62	10·05	10·49	10·88	11·27	11·58	11·88	12·17	12·47	12·75	13·03	13·29	13·54	29
30	9·37	9·64	9·90	10·32	10·75	11·15	11·55	11·86	12·17	12·47	12·77	13·06	18·35	13·61	13·87	30
31	9·56	9·86	10·14	10·56	11·00	11·40	11·80	12·12	12·44	12·75	13·05	13·35	13·64	13·91	14·17	31
32	9·75	10·07	10·38	10·80	11·25	11·65	12·05	12·38	12·71	13·03	13·33	13·64	13·93	14·20	14·46	32
33	9·94	10·28	10·62	11·04	11·50	11·90	12·30	12·64	12·98	13·31	13·61	13·93	14·21	14·49	14·76	33
34	10·13	10·49	10·86	11·28	11·75	12·15	12·55	12·90	13·25	13·59	13·89	14·21	14·50	14·78	15·05	34
35	10·32	10·70	11·10	11·52	12·00	12·40	12·80	13·16	13·52	13·86	14·17	14·49	14·79	15·08	15·34	35
36	10·51	10·91	11·33	11·76	12·24	12·65	13·05	13·42	13·79	14·13	14·45	14·77	15·08	15·37	15·63	36
37	10·70	11·12	11·56	12·00	12·48	12·90	13·30	13·68	14·06	14·40	14·73	15·05	15·37	15·66	15·92	37
38	10·89	11·33	11·79	12·24	12·72	13·14	13·55	13·94	14·33	14·67	15·01	15·33	15·65	15·95	16·21	38
39	11·07	11·54	12·02	12·48	12·96	13·38	13·80	14·20	14·59	14·94	15·29	15·61	15·93	16·25	16·50	39
40	11·25	11·75	12·25	12·72	13·20	13·62	14·05	14·45	14·85	15·21	15·57	15·90	16·22	16·54	16·79	40
41	11·48	11·99	12·48	12·96	13·44	13·84	14·24	14·65	15·06	15·45	15·83	16·18	16·52	16·83	17·08	41
42	11·71	12·23	12·72	13·20	13·68	14·06	14·43	14·85	15·27	15·69	16·09	16·46	16·81	17·12	17·37	42
43	11·94	12·47	12·95	13·44	13·92	14·28	14·62	15·05	15·48	15·93	16·35	16·74	17·11	17·41	17·66	43
44	12·17	12·71	13·19	13·68	14·16	14·50	14·81	15·25	15·69	16·17	16·61	17·02	17·40	17·70	17·94	44
45	12·40	12·94	13·42	13·92	14·40	14·71	15·00	15·45	15·90	16·41	16·87	17·30	17·70	17·99	18·22	45
46	12·63	13·17	13·66	14·16	14·64	14·92	15·19	15·66	16·12	16·65	17·13	17·58	17·99	18·28	18·50	46
47	12·86	13·40	13·89	14·40	14·88	15·13	15·38	15·86	16·33	16·88	17·39	17·86	18·29	18·56	18·78	47
48	13·10	13·63	14·13	14·63	15·11	15·34	15·57	16·06	16·54	17·11	17·65	18·13	18·58	18·84	19·06	48
49	13·33	13·86	14·36	14·86	15·34	15·55	15·76	16·26	16·75	17·34	17·91	18·40	18·88	19·12	19·34	49
50	13·57	14·09	14·60	15·09	15·57	15·76	15·95	16·46	16·97	17·57	18·17	18·67	19·17	19·40	19·62	50
51	13·78	14·31	14·83	15·33	15·81	16·02	16·25	16·75	17·26	17·84	18·42	18·91	19·41	19·65	19·89	51
52	13·99	14·53	15·06	15·57	16·05	16·29	16·55	17·04	17·55	18·11	18·67	19·15	19·64	19·90	20·16	52
53	14·20	14·75	15·29	15·81	16·29	16·55	16·84	17·33	17·84	18·38	18·92	19·39	19·87	20·15	20·43	53
54	14·41	14·97	15·52	16·04	16·53	16·82	17·13	17·62	18·12	18·65	19·17	19·63	20·10	20·40	20·70	54
55	14·62	15·19	15·75	16·27	16·77	17·08	17·42	17·91	18·40	18·92	19·42	19·87	20·33	20·65	20·97	55
56	14·83	15·41	15·98	16·50	17·01	17·35	17·71	18·20	18·68	19·19	19·67	20·11	20·56	20·90	21·23	56
57	15·04	15·63	16·21	16·73	17·25	17·61	18·00	18·48	18·96	19·45	19·92	20·35	20·80	21·15	21·49	57
58	15·25	15·84	16·44	16·96	17·49	17·88	18·29	18·77	19·24	19·71	20·17	20·59	21·03	21·39	21·75	58
59	15·45	16·05	16·67	17·19	17·73	18·14	18·58	19·06	19·52	19·97	20·42	20·83	21·26	21·63	22·01	59
60	15·65	16·26	16·89	17·42	17·96	18·41	18·87	19·34	19·80	20·24	20·67	21·07	21·49	21·87	22·27	60
61	15·92	16·51	17·13	17·65	18·19	18·64	19·11	19·58	20·04	20·48	20·92	21·32	21·74	22·13	22·53	61
62	16·19	16·76	17·37	17·88	18·42	18·87	19·35	19·82	20·28	20·72	21·17	21·57	21·99	22·39	22·79	62
63	16·46	17·01	17·61	18·11	18·65	19·10	19·59	20·06	20·52	20·96	21·42	21·82	22·24	22·64	23·05	63
64	16·73	17·26	17·84	18·34	18·88	19·33	19·83	20·30	20·76	21·20	21·66	22·07	22·49	22·89	23·31	64
65	17·00	17·51	18·07	18·57	19·11	19·56	20·06	20·54	21·00	21·44	21·90	22·32	22·74	23·14	23·56	65
66	17·26	17·76	18·30	18·80	19·33	19·79	20·29	20·77	21·24	21·68	22·14	22·57	22·99	23·39	23·81	66
67	17·52	18·01	18·53	19·03	19·55	20·02	20·52	21·00	21·47	21·92	22·38	22·82	23·24	23·64	24·06	67
68	17·78	18·26	18·76	19·26	19·77	20·25	20·75	21·23	21·71	22·16	22·62	23·06	23·49	23·89	24·31	68
69	18·04	18·51	18·99	19·49	19·99	20·48	20·98	21·46	21·94	22·40	22·86	23·30	23·73	24·14	24·56	69
70	18·30	18·76	19·22	19·71	20·21	20·71	21·21	21·69	22·18	22 64	23·10	23·54	23·97	24·39	24·81	70
71	18·54	19·00	19·45	19·95	20·45	20·93	21·41	21·91	22·42	22·87	23·33	23·77	24·21	24·63	25·07	71
72	18·78	19·24	19·68	20·19	20·69	21·16	21·62	22·13	22·65	23·11	23·57	24·01	24·45	24·88	25·32	72
73	19·02	19·48	19·92	20·43	20·93	21·38	21·82	22·35	22·89	23·34	23·81	24·25	24·70	25·12	25·58	73
74	19·26	19·72	20·15	20·67	21·17	21·61	22·03	22·57	23·12	23·58	24·04	24·49	24·94	25·37	25·83	74
75	19·50	19·96	20·38	20·91	21·41	21·83	22·23	22·79	23·36	23·81	24·28	24·72	25·18	25·62	26·09	75
76	19·74	20·19	20·61	21·15	21·65	22·06	22·44	23·01	23·59	24·05	24·51	24·96	25·42	25·87	26·34	76
77	19·98	20·42	20·84	21·39	21·90	22·28	22·64	23·23	23·82	24·28	24·75	25·20	25·66	26·12	26·59	77
78	20·21	20·65	21·07	21·63	22·15	22·51	22·85	23·45	24·05	24·52	24·99	25·44	25·90	26·37	26·85	78
79	20·44	20·88	21·31	21·87	22·40	22·73	23·05	23·67	24·28	24·75	25·23	25·68	26·14	26·62	27·10	79
80	20·67	21·11	21·55	22·10	22·65	22·96	23·26	23·89	24·51	24·99	25·47	25·92	26·39	26·86	27·35	80
81	20·91	21·35	21·78	22·33	22·87	23·20	23·52	24·13	24·74	25·22	25·70	26·15	26·63	27·10	27·59	81
82	21·15	21·59	22·02	22·56	23·09	23·43	23·77	24·38	24·98	25·46	25·94	26·39	26·87	27·34	27·83	82
83	21·40	21·82	22·25	22·79	23·31	23·67	24·02	24·62	25·21	25·69	26·17	26·62	27·11	27·58	28·07	83
84	21·64	22·06	22·49	23·02	23·53	23·91	24·28	24·87	25·45	25·93	26·41	26·86	27·35	27·82	28·31	84
85	21·89	22·30	22·72	23·25	23·75	24·15	24·54	25·11	25·68	26·16	26·64	27·10	27·59	28·06	28·55	85
86	22·13	22·54	22·95	23·48	23·97	24·39	24·80	25·36	25·91	26·39	26·88	27·34	27·83	28·30	28·79	86
87	22·37	22·78	23·18	23·70	24·19	24·63	25·06	25·60	26·14	26·62	27·11	27·58	28·07	28·54	29·03	87
88	22·61	23·02	23·42	23·92	24·41	24·87	25·32	25·84	26·37	26·85	27·35	27·82	28·31	28·78	29·27	88
89	22·85	23·26	23·65	24·14	24·63	25·11	25·58	26·09	26·60	27·08	27·58	28·06	28·55	29·02	29·51	89
90	23·09	23·49	23·89	24·36	24·84	25·34	25·84	26·34	26·84	27·32	27·82	28·30	28·79	29·26	29·74	90
91	23·33	23·73	24·12	24·59	25·07	25·57	26·07	26·57	27·07	27·56	28·05	28·53	29·03	29·49	29·97	91
92	23·57	23·97	24·36	24·82	25·30	25·80	26·30	26·80	27·30	27·79	28·29	28·77	29·26	29·73	30·21	92
93	23·81	24·20	24·59	25·05	25·54	26·03	26·53	27·03	27·53	28·03	28·52	29·00	29·50	29·96	30·45	93
94	24·05	24·44	24·83	25·28	25·77	26·26	26·76	27·26	27·76	28·26	28·75	29·24	29·73	30·20	30·69	94
95	24·29	24·68	25·06	25·52	26·00	26·49	26·99	27·49	27·99	28·49	28·98	29·47	29·97	30·44	30·92	95
96	24·53	24·92	25·30	25·76	26·23	26·73	27·22	27·72	28·22	28·72	29·21	29·71	30·20	30·67	31·16	96
97	24·77	25·16	25·53	26·00	26·46	26·96	27·45	27·95	28·45	28·95	29·44	29·94	30·43	30·91	81·40	97
98	25·01	25·40	25·77	26·24	26·69	27·19	27·68	28·18	28·68	29·18	29·67	30·17	30·66	31·14	31·64	98
99	25·25	25·64	26·01	26·48	26·92	27·42	27·91	28·42	28·91	29·41	29·90	30·40	30·89	31·38	31·88	99
100	25·50	25·87	26·25	26·70	27·16	27·65	28·15	28·65	29·15	29·65	30·15	30·64	31·12	31·61	32·10	100

Diameter of Cylinder, in Inches.	LAND ENGINES. Thickness of Crank at Centre of Fly Wheel Shaft when of Cast Iron, in Inches.															Diameter of Cylinder, in Inches.
	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	Length of Stroke in Feet
20	3·30	3·40	3·51	3·77	4·03	4·20	4·36	4·49	4·62	4·74	4·86	4·97	5·07	5·18	5·27	20
21	3·44	3·54	3·65	3·91	4·17	4·34	4·50	4·64	4·77	4·89	5·02	5·13	5·23	5·35	5·44	21
22	3·58	3·68	3·80	4·05	4·31	4·48	4·64	4·79	4·92	5·04	5·18	5·29	5·39	5·52	5·61	22
23	3·72	3·82	3·94	4·19	4·45	4·62	4·78	4·94	5·07	5·19	5·33	5·45	5·55	5·68	5·78	23
24	3·86	3·96	4·09	4·33	4·59	4·76	4·92	5·09	5·22	5·34	5·48	5·61	5·71	5·84	5·95	24
25	4·00	4·10	4·23	4·47	4·72	4·90	5·06	5·23	5·37	5·49	5·63	5·77	5·87	6·00	6·12	25
26	4·14	4·24	4·38	4·61	4·85	5·04	5·20	5·37	5·52	5·64	5·78	5·93	6·03	6·16	6·29	26
27	4·28	4·38	4·52	4·75	4·98	5·18	5·34	5·51	5·66	5·79	5·93	6·08	6·19	6·32	6·45	27
28	4·42	4·53	4·66	4·89	5·11	5·31	5·48	5·65	5·80	5·94	6·08	6·23	6·35	6·48	6·61	28
29	4·55	4·67	4·80	5·03	5·24	5·44	5·62	5·79	5·94	6·09	6·23	6·38	6·51	6·64	6·77	29
30	4·68	4·82	4·95	5·16	5·37	5·57	5·77	5·93	6·08	6·23	6·38	6·53	6·67	6·80	6·93	30
31	4·78	4·92	5·07	5·28	5·50	5·70	5·89	6·06	6·22	6·37	6·52	6·68	6·82	6·95	7·08	31
32	4·87	5·03	5·19	5·40	5·63	5·83	6·02	6·19	6·36	6·51	6·66	6·83	6·97	7·10	7·23	32
33	4·97	5·13	5·30	5·52	5·76	5·96	6·14	6·32	6·50	6·65	6·80	6·97	7·12	7·25	7·38	33
34	5·06	5·24	5·42	5·64	5·88	6·09	6·27	6·45	6·64	6·79	6·94	7·11	7·27	7·40	7·53	34
35	5·16	5·34	5·53	5·76	6·00	6·21	6·39	6·58	6·77	6·93	7·08	7·25	7·41	7·55	7·68	35
36	5·25	5·45	5·65	5·88	6·12	6·33	6·52	6·71	6·90	7·07	7·22	7·39	7·55	7·70	7·83	36
37	5·35	5·55	5·76	6·00	6·24	6·45	6·64	6·84	7·03	7·21	7·36	7·53	7·69	7·85	7·97	37
38	5·44	5·66	5·88	6·12	6·36	6·57	6·77	6·97	7·16	7·34	7·50	7·67	7·83	7·99	8·11	38
39	5·53	5·76	6·00	6·24	6·48	6·69	6·89	7·10	7·29	7·47	7·64	7·81	7·97	8·13	8·25	39
40	5·62	5·87	6·12	6·36	6·60	6·81	7·02	7·22	7·42	7·60	7·78	7·95	8·11	8·27	8·39	40
41	5·73	5·98	6·23	6·48	6·72	6·92	7·12	7·32	7·53	7·72	7·91	8·09	8·26	8·42	8·54	41
42	5·85	6·10	6·35	6·60	6·84	7·03	7·21	7·42	7·64	7·84	8·04	8·23	8·41	8·57	8·68	42
43	5·96	6·21	6·47	6·72	6·98	7·14	7·31	7·52	7·75	7·96	8·17	8·36	8·56	8·72	8·82	43
44	6·08	6·33	6·59	6·83	7·08	7·25	7·40	7·63	7·86	8·08	8·30	8·49	8·71	8·86	8·96	44
45	6·20	6·45	6·71	6·95	7·20	7·36	7·50	7·73	7·97	8·20	8·43	8·63	8·86	9·00	9·10	45
46	6·31	6·56	6·83	7·07	7·32	7·47	7·59	7·83	8·08	8·32	8·56	8·77	9·01	9·14	9·24	46
47	6·43	6·67	6·95	7·19	7·44	7·58	7·69	7·93	8·18	8·44	8·69	8·91	9·16	9·28	9·38	47
48	6·54	6·79	7·07	7·31	7·56	7·68	7·78	8·03	8·28	8·56	8·82	9·05	9·30	9·42	9·52	48
49	6·66	6·91	7·19	7·42	7·67	7·78	7·88	8·13	8·38	8·67	8·95	9·19	9·44	9·56	9·66	49
50	6·78	7·04	7·30	7·54	7·78	7·88	7·97	8·23	8·48	8·78	9·08	9·33	9·58	9·70	9·81	50
51	6·89	7·15	7·42	7·66	7·90	8·01	8·11	8·37	8·62	8·92	9·21	9·45	9·70	9·83	9·95	51
52	6·99	7·26	7·53	7·77	8·02	8·14	8·26	8·52	8·76	9·06	9·34	9·57	9·82	9·96	10·09	52
53	7·10	7·37	7·65	7·89	8·14	8·27	8·40.	8·66	8·90	9·20	9·47	9·69	9·94	10·09	10·22	53
54	7·20	7·48	7·76	8·00	8·26	8·40	8·55	8·81	9·05	9·34	9·60	9·81	10·06	10·21	10·35	54
55	7·31	7·59	7·88	8·12	8·38	8·53	8·69	8·95	9·19	9·47	9·73	9·93	10·18	10·33	10·48	55
56	7·41	7·70	7·99	8·24	8·50	8·66	8·84	9·10	9·33	9·60	9·85	10·05	10·30	10·45	10·61	56
57	7·51	7·81	8·10	8·36	8·62	8·79	8·98	9·24	9·47	9·73	9·97	10·17	10·41	10·57	10·74	57
58	7·62	7·92	8·21	8·48	8·74	8·92	9·13	9·39	9·61	9·86	10·09	10·29	10·52	10·69	10·87	58
59	7·72	8·03	8·32	8·60	8·86	9·05	9·27	9·53	9·75	9·99	10·21	10·41	10·63	10·81	11·00	59
60	7·82	8·13	8·44	8·71	8·98	9·20	9·43	9·67	9·90	10·12	10·33	10·53	10·74	10·93	11·13	60
61	7·96	8·26	8·56	8·83	9·10	9·32	9·55	9·79	10·02	10·24	10·46	10·66	10·87	11·06	11·26	61
62	8·10	8·39	8·68	8·95	9·22	9·43	9·67	9·91	10·14	10·36	10·59	10·79	11·00	11·19	11·39	62
63	8·24	8·52	8·80	9·07	9·33	9·55	9·79	10·03	10·26	10·48	10·71	10·92	11·13	11·32	11·52	63
64	8·37	8·65	8·92	9·18	9·44	9·66	9·91	10·15	10·38	10·60	10·83	11·05	11·26	11·45	11·65	64
65	8·50	8·78	9·04	9·30	9·55	9·78	10·03	10·27	10·50	10·72	10·95	11·17	11·39	11·58	11·78	65
66	8·63	8·90	9·16	9·41	9·66	9·89	10·15	10·39	10·62	10·84	11·07	11·29	11·52	11·71	11·91	66
67	8·76	9·02	9·28	9·52	9·77	10·01	10·27	10·51	10·74	10·96	11·19	11·42	11·64	11·83	12·04	67
68	8·89	9·14	9·39	9·63	9·88	10·12	10·38	10·62	10·86	11·08	11·31	11·55	11·76	11·95	12·16	68
69	9·02	9·26	9·51	9·74	9·99	10·24	10·49	10·73	10·98	11·20	11·43	11·68	11·88	12·07	12·28	69
70	9·15	9·38	9·61	9·85	10·10	10·35	10·60	10·84	11·09	11·32	11·55	11·77	11·98	12·19	12·40	70
71	9·27	9·50	9·72	9·97	10·23	10·47	10·71	10·95	11·20	11·44	11·66	11·88	12·10	12·31	12·53	71
72	9·39	9·62	9·84	10·09	10·35	10·58	10·81	11·06	11·32	11·55	11·77	12·00	12·22	12·43	12·65	72
73	9·51	9·74	9·95	10·21	10·47	10·70	10·92	11·17	11·44	11·67	11·89	12·12	12·34	12·56	12·78	73
74	9·63	9·86	10·07	10·33	10·59	10·81	11·02	11·28	11·55	11·79	12·01	12·24	12·46	12·68	12·90	74
75	9·75	9·98	10·18	10·45	10·71	10·92	11·13	11·39	11·67	11·91	12·13	12·36	12·58	12·80	13·03	75
76	9·87	10·10	10·30	10·57	10·83	11·03	11·23	11·50	11·78	12·02	12·25	12·48	12·70	12·93	13·16	76
77	9·99	10·22	10·41	10·69	10·95	11·14	11·33	11·61	11·90	12·14	12·37	12·60	12·82	13·05	13·29	77
78	10·11	10·33	10·53	10·81	11·07	11·25	11·43	11·72	12·01	12·25	12·49	12·72	12·94	13·18	13·42	78
79	10·22	10·44	10·65	10·93	11·19	11·36	11·53	11·83	12·13	12·37	12·61	12·84	13·06	13·30	13·55	79
80	10·33	10·55	10·77	11·05	11·32	11·48	11·63	11·94	12·25	12·49	12·73	12·96	13·19	13·43	13·67	80
81	10·45	10·66	10·89	11·15	11·43	11·60	11·76	12·06	12·36	12·61	12·85	13·08	13·31	13·55	13·79	81
82	10·57	10·78	11·00	11·27	11·54	11·72	11·89	12·19	12·48	12·72	12·96	13·20	13·43	13·67	13·91	82
83	10·69	10·90	11·12	11·38	11·65	11·84	12·02	12·31	12·60	12·84	13·08	13·32	13·55	13·79	14·03	83
84	10·81	11·02	11·24	11·50	11·76	11·96	12·15	12·44	12·71	12·96	13·20	13·44	13·67	13·91	14·15	84
85	10·93	11·14	11·35	11·61	11·87	12·08	12·28	12·56	12·83	13·07	13·32	13·56	13·79	14·03	14·27	85
86	11·05	11·26	11·47	11·72	11·98	12·20	12·41	12·68	12·94	13·19	13·44	13·68	13·91	14·15	14·39	86
87	11·17	11·38	11·59	11·83	12·09	12·32	12·54	12·80	13·06	13·30	13·56	13·79	14·03	14·27	14·51	87
88	11·29	11·50	11·70	11·95	12·20	12·44	12·67	12·92	13·17	13·42	13·68	13·91	14·15	14·39	14·63	88
89	11·41	11·62	11·82	12·06	12·31	12·56	12·80	13·04	13·29	13·53	13·80	14·03	14·27	14·51	14·75	89
90	11·54	11·74	11·94	12·18	12·42	12·67	12·92	13·17	13·42	13·66	13·91	14·15	14·39	14·63	14·87	90
91	11·66	11·85	12·06	12·30	12·53	12·79	13·03	13·29	13·54	13·78	14·03	14·27	14·51	14·74	14·98	91
92	11·78	11·97	12·18	12·41	12·65	12·90	13·15	13·40	13·65	13·90	14·14	14·38	14·62	14·86	15·10	92
93	11·90	12·09	12·30	12·53	12·76	13·02	13·26	13·52	13·77	14·01	14·26	14·50	14·74	14·98	15·22	93
94	12·02	12·21	12·42	12·64	12·88	13·13	13·38	13·63	13·88	14·12	14·37	14·62	14·85	15·09	15·34	94
95	12·14	12·33	12·54	12·76	12·99	13·25	13·49	13·75	14·00	14·24	14·49	14·74	14·97	15·21	15·56	95
96	12·26	12·45	12·66	12·87	13·11	13·36	13·61	13·86	14·11	14·36	14·61	14·86	15·09	15·33	15·68	96
97	12·38	12·57	12·78	12·99	13·22	13·48	13·72	13·98	14·23	14·47	14·72	14·97	15·21	15·45	15·80	97
98	12·50	12·69	12·90	13·10	13·34	13·59	13·84	14·09	14·34	14·58	14·84	15·09	15·33	15·57	15·92	98
99	12·62	12·81	13·01	13·22	13·45	13·71	13·95	14·21	14·46	14·70	14·95	15·20	15·45	15·69	16·04	99
100	12·75	12·93	13·12	13·35	13·58	13·82	14·07	14·32	14·57	14·82	15·07	15·32	15·56	15·80	16·05	100

Diameter of Cylinder in Inches.	Land Engines. Diameter of Fly-Wheel Shaft, when of Cast Iron, in Inches.															Diameter of Cylinder in Inches.
	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	
21	5·29	5·67	6·02	6·31	6·62	6·87	7·14	7·36	7·59	7·79	7·99	8·17	8·35	8·50	8·69	21
22	5·45	5·81	6·20	6·50	6·82	7·08	7·36	7·59	7·82	8·03	8·23	8·42	8·61	8·75	8·96	22
23	5·61	5·95	6·38	6·69	7·02	7·29	7·58	7·82	8·05	8·27	8·47	8·67	8·87	9·01	9·23	23
24	5·78	6·09	6·56	6·88	7·22	7·50	7·80	8·05	8·28	8·51	8·71	8·92	9·12	9·27	9·49	24
25	5·94	6·23	6·74	7·07	7·42	7·71	8·02	8·27	8·51	8·75	8·95	9·16	9·37	9·53	9·75	25
26	6·11	6·37	6·92	7·26	7·62	7·92	8·23	8·49	8·74	8·98	9·19	9·40	9·62	9·78	10·01	26
27	6·27	6·51	7·10	7·45	7·82	8·13	8·44	8·71	8·97	9·21	9·43	9·64	9·87	10·04	10·27	27
28	6·44	6·65	7·28	7·64	8·02	8·34	8·65	8·93	9·20	9·44	9·67	9·88	10·12	10·29	10·53	28
29	6·60	6·79	7·46	7·83	8·22	8·55	8·86	9·15	9·43	9·67	9·91	10·12	10·37	10·55	10·79	29
30	6·77	7·09	7·65	8·02	8·42	8·74	9·07	9·36	9·65	9·90	10·15	10·37	10·61	10·81	11·04	30
31	6·91	7·25	7·81	8·19	8·60	8·93	9·26	9·56	9·86	10·11	10·37	10·59	10·84	11·04	11·28	31
32	7·05	7·41	7·97	8·36	8·78	9·12	9·45	9·76	10·07	10·32	10·59	10·81	11·07	11·27	11·52	32
33	7·19	7·57	8·13	8·53	8·96	9·31	9·64	9·96	10·28	10·53	10·81	11·03	11·30	11·50	11·76	33
34	7·33	7·73	8·29	8·70	9·14	9·50	9·83	10·16	10·49	10·74	11·03	11·25	11·53	11·73	11·99	34
35	7·47	7·89	8·45	8·87	9·32	9·69	10·02	10·36	10·69	10·95	11·24	11·47	11·76	11·96	12·22	35
36	7·61	8·05	8·61	9·04	9·50	9·87	10·21	10·56	10·89	11·16	11·45	11·69	11·98	12·19	12·45	36
37	7·75	8·21	8·77	9·21	9·68	10·05	10·40	10·76	11·09	11·37	11·66	11·91	12·20	12·42	12·68	37
38	7·89	8·37	8·93	9·38	9·86	10·23	10·59	10·96	11·29	11·58	11·87	12·13	12·43	12·65	12·91	38
39	8·04	8·54	9·09	9·55	10·03	10·41	10·79	11·15	11·49	11·79	12·08	12·35	12·66	12·88	13·14	39
40	8·19	8·72	9·27	9·72	10·20	10·59	10·99	11·34	11·69	11·99	12·29	12·56	12·86	13·11	13·37	40
41	8·30	8·86	9·41	9·88	10·37	10·76	11·18	11·52	11·88	12·19	14·49	12·77	13·07	13·32	13·59	41
42	8·41	9·00	9·56	10·04	10·53	10·93	11·36	11·70	12·07	12·38	14·69	12·98	13·28	13·53	13·81	42
43	8·52	9·14	9·71	10·20	10·69	11·10	11·54	11·88	12·26	12·57	14·89	13·19	13·49	13·74	14·03	43
44	8·63	9·28	9·86	10·36	10·85	11·27	11·72	12·06	12·45	12·76	15·09	13·39	13·70	13·95	14·25	44
45	8·75	9·42	10·01	10·52	11·01	11·44	11·90	12·24	12·64	12·95	15·29	13·59	13·91	14·16	14·46	45
46	8·87	9·56	10·16	10·67	11·17	11·61	12·07	12·42	12·83	13·14	15·49	13·79	14·12	14·37	14·67	46
47	8·99	9·70	10·31	10·82	11·33	11·78	12·24	12·60	13·01	13·33	15·69	13·99	14·32	14·58	14·88	47
48	9·11	9·84	10·46	10·97	11·49	11·95	12·41	12·78	13·19	13·52	15·89	14·19	14·52	14·79	15·09	48
49	9·23	9·98	10·61	11·12	11·65	12·11	12·58	12·96	13·37	13·71	16·08	14·39	14·72	15·00	15·30	49
50	9·35	10·12	10·76	11·27	11·82	12·27	12·75	13·14	13·55	13·90	14·27	14·59	14·92	15·21	15·51	50
51	9·47	10·25	10·90	11·42	11·97	12·43	12·92	13·32	13·73	14·08	14·46	14·78	15·12	15·41	15·72	51
52	9·59	10·38	11·04	11·57	12·12	12·59	13·09	13·50	13·91	14·26	14·65	14·97	15·32	15·61	15·92	52
53	9·71	10·51	11·18	11·72	12·27	12·76	13·26	13·67	14·09	14·44	14·84	15·16	15·52	15·81	16·12	53
54	9·83	10·64	11·32	11·87	12·42	12·93	13·43	13·84	14·27	14·62	15·03	15·35	15·71	16·01	16·32	54
55	9·96	10·77	11·46	12·02	12·57	13·10	13·60	14·01	14·45	14·80	15·21	15·54	15·90	16·21	16·52	55
56	10·09	10·90	11·60	12·17	12·73	13·26	13·77	14·18	14·63	14·98	15·39	15·73	16·09	16·41	16·72	56
57	10·22	11·03	11·74	12·32	12·89	13·42	13·94	14·35	14·80	15·16	15·57	15·92	16·28	16·60	16·92	57
58	10·35	11·16	11·88	12·47	13·05	13·58	14·11	14·52	14·97	15·34	15·75	16·10	16·47	16·79	17·12	58
59	10·48	11·30	12·02	12·61	13·21	13·74	14·28	14·69	15·14	15·52	15·93	16·28	16·66	16·98	17·32	59
60	10·61	11·44	12·15	12·75	13·37	13·90	14·44	14·86	15·31	15·70	16·11	16·46	16·85	17·17	17·52	60
61	10·73	11·57	12·29	12·88	13·49	14·04	14·60	15·02	15·48	15·87	16·29	16·64	17·04	17·36	17·71	61
62	10·85	11·70	12·42	13·01	13·61	14·18	14·75	15·18	15·65	16·04	16·47	16·82	17·23	17·55	17·90	62
63	10·97	11·83	12·55	13·14	13·73	14·32	14·90	15·34	15·82	16·21	16·65	17·00	17·41	17·74	18·09	63
64	11·09	11·95	12·68	13·27	13·85	14·46	15·05	15·50	15·99	16·38	16·83	17·18	17·59	17·93	18·28	64
65	11·21	12·07	12·81	13·39	13·97	14·60	15·20	15·66	16·16	16·55	17·01	17·36	17·77	18·12	18·47	65
66	11·32	12·19	12·94	13·51	14·09	14·73	15·35	15·82	16·32	16·72	17·18	17·54	17·95	18·31	18·66	66
67	11·43	12·31	13·07	13·63	14·21	14·86	15·50	15·98	16·48	16·89	17·35	17·72	18·13	18·50	18·85	67
68	11·54	12·43	13·20	13·75	14·33	14·99	15·65	16·14	16·64	17·06	17·52	17·90	18·31	18·68	19·04	68
69	11·65	12·55	13·33	13·87	14·44	15·12	15·80	16·30	16·80	17·23	17·69	18·08	18·49	18·86	19·23	69
70	11·76	12·67	13·46	13·99	14·55	15·25	15·96	16·45	16·96	17·40	17·86	18·25	18·67	19·04	19·42	70
71	11·87	12·79	13·59	14·13	14·72	15·40	16·11	16·61	17·12	17·57	18·03	18·48	18·85	19·22	19·60	71
72	11·98	12·91	13·72	14·27	14·89	15·55	16·26	16·77	17·28	17·74	18·20	18·65	19·03	19·40	19·78	72
73	12·09	13·03	13·85	14·41	15·06	15·70	16·41	16·92	17·44	17·90	18·37	18·82	19·21	19·58	19·96	73
74	12·20	13·15	13·98	14·55	15·23	15·85	16·56	17·07	17·60	18·06	18·54	18·99	19·39	19·76	20·14	74
75	12·31	13·27	14·10	14·69	15·40	16·00	16·71	17·22	17·76	18·22	18·71	19·16	19·56	19·94	20·32	75
76	12·42	13·39	14·22	14·82	15·56	16·15	16·86	17·37	17·92	18·38	18·88	19·33	19·73	20·11	20·50	76
77	12·53	13·51	14·34	14·95	15·72	16·30	17·01	17·52	18·08	18·54	19·04	19·50	19·90	20·28	20·68	77
78	12·64	13·63	14·46	15·08	15·88	16·44	17·16	17·67	18·24	18·70	19·20	19·67	20·07	20·45	20·86	78
79	12·75	13·74	14·58	15·21	16·04	16·58	17·31	17·82	18·40	18·86	19·36	19·84	20·24	20·62	21·04	79
80	12·86	13·85	14·70	15·34	16·20	16·72	17·45	17·97	18·55	19·02	19·52	19·96	20·41	20·79	21·22	80
81	12·97	13·91	14·83	15·48	16·33	16·87	17·60	18·12	18·71	19·18	19·68	20·13	20·58	20·97	21·40	81
82	13·08	13·97	14·96	15·62	16·46	17·02	17·75	18·27	18·86	19·34	19·84	20·29	20·75	21·15	21·58	82
83	13·19	14·03	15·08	15·76	16·59	17·17	17·89	18·42	19·01	19·50	20·00	20·45	20·92	21·32	21·76	83
84	13·30	14·09	15·20	15·89	16·72	17·32	18·03	18·57	19·16	19·66	20·16	20·61	21·09	21·49	21·94	84
85	13·41	14·14	15·32	16·02	16·85	17·47	18·17	18·72	19·31	19·81	20·32	20·77	21·26	21·66	22·11	85
86	13·51	14·19	15·44	16·15	16·98	17·61	18·31	18·87	19·46	19·96	20·48	20·93	21·42	21·83	22·28	86
87	13·61	14·24	15·56	16·28	17·11	17·75	18·45	19·02	19·61	20·11	20·64	21·09	21·58	22·00	22·45	87
88	13·71	14·29	15·68	16·41	17·24	17·89	18·59	19·17	19·76	20·26	20·80	21·25	21·74	22·17	22·62	88
89	13·81	14·34	15·80	16·54	17·37	18·03	18·73	19·31	19·91	20·41	20·96	21·41	21·90	22·34	22·79	89
90	13·91	14·39	15·92	16·67	17·50	18·17	18·87	19·45	20·06	20·56	21·11	21·57	22·07	22·51	22·96	90
91	14·01	14·56	16·04	16·76	17·63	18·31	19·01	19·60	20·21	20·72	21·29	21·73	22·24	22·68	23·13	91
92	14·11	14·73	16·16	16·85	17·76	18·45	19·15	19·75	20·36	20·87	21·47	21·89	22·41	22·85	23·30	92
93	14·21	14·90	16·28	16·94	17·89	18·59	19·29	19·90	20·51	21·02	21·65	22·05	22·57	23·02	23·47	93
94	14·31	15·07	16·40	17·03	18·02	18·73	19·43	20·05	20·66	21·17	21·83	22·21	22·73	23·19	23·64	94
95	14·41	15·24	16·52	17·11	18·15	18·86	19·57	20·19	20·81	21·32	22·01	22·37	22·89	23·35	23·81	95
96	14·51	15·41	16·63	17·19	18·28	18·99	19·71	20·33	20·96	21·47	22·19	22·53	23·05	23·51	23·98	96
97	14·61	15·58	16·74	17·27	18·41	19·12	19·85	20·47	21·10	21·62	22·37	22·69	23·21	23·67	24·15	97
98	14·71	15·74	16·85	17·35	18·54	19·25	19·99	20·61	21·24	21·77	22·55	22·85	23·37	23·83	24·32	98
99	14·81	15·90	16·96	17·43	18·67	19·38	20·12	20·75	21·38	21·92	22·73	23·00	23·53	23·99	24·48	99
100	14.91	16·06	17·07	17·51	18·80	19·51	20·25	20·89	21·52	22·07	22·90	23·15	23·69	24·15	24·64	100

TABLE A.

Table of Numbers for finding the Sectional Area, in Square Inches, of the Fly-Wheel Rim.

Length of Stroke in Feet.

Diameter of Cylinder in Inches.	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	Diameter of Cylinder in Inches.
20	36·00	31·02	27·50	24·79	22·68	20·97	19·54	18·34	17·31	16·41	15·62	14·91	14·29	13·72	13·21	20
21	40·00	34·51	30·59	27·57	25·23	23·33	21·74	20·40	19·25	18·25	17·37	16·58	15·89	15·26	14·69	21
22	44·02	38·00	33·68	30·35	27·78	25·69	23·94	22·46	21·19	20·09	19·12	18·25	17·49	16·80	16·17	22
23	48·06	41·49	36·77	33·13	30·33	28·05	26·14	24·52	23·13	21·93	20·87	19·92	19·10	18·34	17·65	23
24	52·10	44·98	39·86	35·91	32·88	30·41	28·34	26·58	25·07	23·78	22·62	21·60	20·70	19·88	19·14	24
25	56·24	48·47	42·95	38·73	35·43	32·77	30·54	28·65	27·05	25·64	24·40	23·30	22·32	21·44	20·64	25
26	61·14	52·73	46·72	42·13	38·54	35·65	33·22	31·17	29·43	27·89	26·54	25·35	24·28	23·32	22·45	26
27	66·09	56·99	50·49	45·54	41·65	38·53	35·90	33·69	31·81	30·14	28·69	27·40	26·24	25·20	24·26	27
28	71·09	61·25	54·26	48·94	44·76	41·11	38·58	36·21	34·19	32·39	30·83	29·45	28·20	27·08	26·07	28
29	76·14	65·52	58·03	52·35	47·88	43·99	41·26	38·73	36·57	34·64	32·97	31·50	30·16	28·96	27·88	29
30	80·99	69·81	61·84	55·77	51·02	47·18	43·97	41·26	38·96	36·91	35·14	33·56	32·14	30·87	29·71	30
31	86·84	74·84	66·30	59·81	54·70	50·58	47·14	44·24	41·77	39·57	37·67	35·98	34·46	33·10	31·85	31
32	92·69	79·87	70·76	63·85	58·38	53·99	50·31	47·22	44·58	42·23	40·20	38·40	36·78	35·33	33·99	32
33	98·54	84·90	75·22	67·89	62·06	57·39	53·48	50·20	47·39	44·89	42·73	40·82	39·10	37·56	36·13	33
34	104·39	89·94	79·68	71·94	65·74	60·80	56·65	53·18	50·20	47·56	45·27	43·24	41·42	39·79	38·27	34
35	110·24	95·00	84·17	75·91	69·45	64·22	59·85	56·16	53·02	50·24	47·83	45·67	43·75	42·02	40·44	35
36	116·99	100·81	89·33	80·56	73·70	68·15	63·51	59·60	56·26	53·32	50·76	48·46	46·43	44·59	42·92	36
37	123·74	106·62	94·49	85·21	77·95	72·08	67·17	63·04	59·50	56·40	53·69	51·25	49·11	47·16	45·40	37
38	130·49	112·43	99·65	89·86	82·20	76·01	70·83	66·48	62·74	59·48	56·62	54·04	51·79	49·73	47·88	38
39	137·24	118·25	104·81	94·51	86·45	79·94	74·49	69·92	65·98	62·56	59·55	56·83	54·47	52·30	50·36	39
40	144·00	124·08	110·00	99·16	90·72	83·88	78·16	73·36	69·24	65·64	62·48	59·64	57·16	54·88	52·84	40
41	151·64	130·67	115·82	104·42	95·53	88·33	82·31	77·25	72·92	69·12	65·79	62·81	60·19	57·79	55·64	41
42	159·28	137·26	121·64	109·68	100·34	92·78	86·46	81·14	76·60	72·60	69·10	65·98	63·22	60·70	58·44	42
43	166·92	143·85	127·46	114·94	105·15	97·23	90·61	85·03	80·28	76·08	72·41	69·15	66·25	63·61	61·24	43
44	174·57	150·44	133·29	120·20	109·97	101·69	94·77	88·92	83·96	79·56	75·73	72·32	69·28	66·52	64·05	44
45	182·23	157·07	139·14	125·48	114·80	106·17	98·94	92·84	87·66	83·05	79·06	75·51	72·31	69·46	66·85	45
46	190·78	164·43	145·67	131·37	120·18	111·15	103·58	97·19	91·77	86·94	82·77	79·05	75·70	72·71	69·98	46
47	199·33	171·79	122·20	137·26	125·56	116·13	108·22	101·54	95·88	90·83	86·48	82·59	79·09	75·96	73·11	47
48	207·88	179·15	128·73	143·15	130·94	121·11	112·86	105·89	99·99	94·72	90·19	86·13	82·48	79·21	76·24	48
49	216·43	186·52	135·26	149·04	136·32	126·09	117·50	110·24	104·10	98·61	93·90	89·67	85·87	82·46	79·37	49
50	224·98	193·89	171·80	154·93	141·73	131·07	122·14	114·61	108·21	102·54	97·61	93·21	89·29	85·75	82·54	50
51	234·43	202·03	179·01	161·43	147·68	136·57	127·27	119·42	112 75	106·84	101·70	97·12	93·04	89·35	86·00	51
52	243·88	210·17	186·22	167·93	153·63	142·07	132·40	124·23	117·29	111·14	105·79	101·03	96·79	92·95	89·46	52
53	253·33	218·31	193·43	174·44	159·58	147·58	137·53	129·04	121·83	115·45	109·88	104·94	100·54	96·55	92·92	53
54	262·79	226·45	200·64	180·95	165·53	153·09	142·66	133·85	126·37	119·76	113·98	108·86	104·29	100·16	96·38	54
55	272·25	234·60	207·86	187·46	171·50	158·60	147·79	138·67	130·94	124·07	118·10	112·79	108·04	103·76	99·87	55
56	282·59	243·52	215·76	194·58	178·02	164·62	153·40	143·94	135·92	128·78	122·59	117·08	112·14	107·70	103·66	56
57	292·93	252·44	223·66	201·70	184·54	170·64	159·01	149 21	140·90	133·49	127·08	121·37	116·25	111·64	107·45	57
58	303·27	261·36	231·56	208·82	191·06	176·66	164·62	154·48	145·88	138·20	131·57	125·66	120·35	115·58	111·24	58
59	313·61	270·28	239·46	215·94	197·58	182·69	170·23	159·75	150·86	142·91	136·06	129·95	124·45	119·52	115·03	59
60	323·96	279·24	247·36	223·08	204·10	188·74	175·88	165·04	155·84	147·64	140·56	134·24	128·56	123·48	118·84	60
61	325·21	288·92	255·95	230·83	211·18	195·29	181·98	170·76	161·24	152·76	145·44	138·89	133·02	127·76	122·96	61
62	336·46	298·60	264·54	238·58	218·26	201·84	188·08	176·48	166·64	157·88	150·32	143·54	137·48	132·04	127·08	62
63	347·71	308·28	273·13	246·33	225·34	208·39	194·19	182·20	172·05	163·00	155·20	148·19	141·94	136·32	131·20	63
64	358·96	317·96	281·72	254·08	232·42	214·95	200·30	187·93	177·46	168·13	160·08	152·84	146·40	140·61	135·32	64
65	380·25	327·66	290·32	261·83	239·52	221·51	206·42	193·68	182·88	173·28	164·96	157·53	150·89	144·92	139·48	65
66	392·39	338·13	299·59	270·19	247·17	228·58	213·01	199·87	188·72	178·81	170·23	162·56	155·71	149·55	143·93	66
67	404·53	348·60	308·86	278·55	254·82	235·65	219·61	206·06	194·56	184·34	175·50	167·59	160·53	154·18	148·38	67
68	416·67	359·07	318·13	286·91	262·47	242·72	226·20	212·25	200·40	189·87	180·77	172·62	165·35	158·81	152·83	68
69	428·81	369·54	327·30	295·27	270·12	249·80	232·79	218·44	206·25	195·41	186·04	177·65	170·17	163·44	157·28	69
70	440·97	380·02	336·70	303·66	277·79	256·90	239·40	224·63	212·10	200·97	191·31	182·70	175·00	168·07	161·77	70
71	454·93	391·26	346·67	312·64	286·00	264·50	246·49	231·27	218·37	206·92	196·97	188·10	180·17	173·04	166·56	71
72	468·89	402·50	356·64	321·62	294·21	272·10	253·58	237·91	224·64	212·87	202·62	193·50	185·34	178·01	171·35	72
73	482·85	413·74	366·61	330·60	302·42	279·71	260·67	244·55	230·91	218·82	208·27	198·90	190·51	182·98	176·14	73
74	496·81	424·98	376·58	339·58	310·64	287·32	267·76	251·19	237·18	224·77	213·92	204·30	195·68	187·95	180·93	74
75	506·16	436·23	386·55	348·57	318·87	294·93	274·86	257·85	243·45	230·76	219·60	209·70	200·88	192·96	185·76	75
76	520·12	448·24	397·24	358·18	327·67	503·04	282·41	264·96	250·15	237·12	225·66	215·47	206·43	198·27	190·88	76
77	534·08	460·25	407·93	367·79	336·47	311·15	289·96	272·07	256·85	243·48	231·72	221·24	211·98	203·58	196·00	77
78	548·04	472·26	418·62	377·40	345·27	319·26	297·51	279·19	263·55	249·84	237·78	227·01	217·53	208·89	201·12	78
79	562·01	484·27	429·31	387·01	354·08	327·37	305·07	286·30	270·26	256·20	243·84	232·78	223·08	214·20	206·24	79
80	576·00	496·32	440·00	396·64	362·88	335·52	312·64	293·44	276·96	262·56	249·92	238·56	228·64	219·52	211·36	80
81	590·84	509·11	451·29	406·86	372·22	344·17	320·71	300·99	284·11	269·31	256·35	244·72	234·52	225·98	216·79	81
82	605·68	521·90	462·58	417·08	381·56	352·82	328·78	308·54	291·26	276·06	262·78	250·88	240·40	232·44	222·22	82
83	620·52	534·69	473·87	427·30	390·90	361·47	336·85	316·09	298·41	282·81	269·21	257·04	246·28	238·90	227·65	83
84	635·36	547·48	485·16	437·52	400·24	370·13	344·92	323·64	305·57	289·56	275·64	263·20	252·16	245·36	233·08	84
85	650·21	560·31	496·46	447·74	409·61	378·80	352·99	331·21	312·74	296·33	282·08	269·39	258·04	247·82	238·53	85
86	665·95	573·90	508·48	458·57	419·53	387·97	361·54	339·23	320·32	303·50	288·91	275·92	264·28	253·82	244·30	86
87	681·69	587·49	520·50	469·40	429·45	397·14	370·09	347·25	327·90	310·67	295·74	282·45	270·52	259·82	250·07	87
88	697·43	601·08	532·52	480·23	439·37	406·31	378·64	355·27	335·48	317·84	302·57	288·98	276·76	265·83	255·84	88
89	713·17	614·67	544·54	491·07	449·29	415·48	387·15	363·29	343·06	325·01	309·40	295·51	283·00	271·83	261·61	89
90	728·91	628·29	556·56	501·93	459·22	424·67	395·74	371·34	350·64	332·19	316·26	302·04	289·26	277·83	267·39	90
91	745·57	642·62	569·27	513·40	469·70	434·37	404·77	379·81	358·64	340·18	323·44	308·93	295·87	284·17	273·50	91
92	762·23	656·95	581·98	524·87	480·18	444·07	413·80	388·28	366·64	348·17	330·66	315·82	302·48	290·51	279·61	92
93	778·89	671·28	594·69	536·34	490·66	453·77	422·84	396·75	374·64	356·16	337·88	322·71	309·09	296·85	285·72	93
94	795·55	685·61	607·40	547·81	501·14	463·47	431·87	405·23	382·65	364·15	345·10	329·60	315·70	303·19	291·83	94
95	812·25	699·94	620·15	559·29	511·65	473·17	440·93	413·73	390·65	372·15	352·36	336·50	322·32	309·56	297·95	95
96	829·78	715·06	633·56	571·37	522·70	483·39	450·45	422·67	399·08	379·75	359·97	343·76	329·28	316·24	304·39	96
97	847·31	730·18	646·97	583·45	533·75	493·61	459·97	431·61	407·51	387·35	367·58	351·02	336·24	322·92	310·83	97
98	864·84	745·30	660·38	595·53	544·80	503·83	469·49	440·55	415·94	394·95	375·19	358·28	343·20	329·60	317·27	98
99	882·37	760·42	673·79	607·61	555·85	514·05	479·01	449·49	424·38	402·56	382·80	365·54	350·16	336·28	323·71	99
100	899·92	775·56	687·20	619·72	566 92	524·28	488·56	458·44	432·84	410·16	390·44	372·84	357·16	343·00	330·16	100

TABLE B.

Rule.—Multiply the Number given in Table A corresponding to the length of Stroke and the Diameter of the Cylinder of the given Engine, by the Number in Table B corresponding to the length of the Stroke and mean Diameter of Fly Wheel: the Product is the Sectional Area of the Rim of Fly Wheel in Square Inches.

Mean Diameter of the Fly Wheel in Feet.	Length of Stroke in Feet.															Mean Diameter of the Fly Wheel in Feet.
	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	
0·5	2744	5309	9261	14706	21952	31256	42475	57067	74088	94196	117649	143353	175666	210645	250047	0·5
1	343	664	1158	1713	2744	3907	5309	7133	9261	11774	14706	17919	21958	26331	31256	1
1·5	102	197	343	545	813	1158	1573	2114	2744	3489	4357	5309	6506	7802	9261	1·5
2	43	83	145	214	343	488	664	892	1158	1472	1838	2240	2745	3291	3907	2
2·5	22	42	74	118	176	250	340	457	593	754	941	1147	1405	1685	2000	2·5
3	12	25	43	68	102	145	199	264	343	436	545	670	813	975	1161	3
3·5	8	16	27	43	64	91	125	166	216	275	343	422	512	614	729	3·5
4	5	10	18	27	43	61	83	111	145	184	230	280	343	411	488	4
4·5	3·44	7·30	12·70	20·19	30·11	42·89	58·26	78·30	101·63	119·22	161·34	196·63	240·96	288·96	343	4·5
5	2·75	5·25	9·25	14·75	22·00	31·25	42·50	57·12	74·12	94·25	117·60	143·40	175·60	210·60	250	5
5·5	2·06	4·03	6·96	11·05	16·49	23·49	32·21	42·87	55·65	70·77	88·39	108·70	131·90	158·26	187·90	5·5
6	1·50	3·12	5·37	8·50	12·75	18·12	24·87	33·00	42·87	54·50	68·12	83·75	101·62	121·87	145·12	6
6·5	1·30	2·53	4·30	6·89	10·32	14·68	20·23	26·80	34·86	44·40	55·46	68·22	82·80	99·28	118·09	6·5
7	1·00	2·00	3·37	5·37	8·00	11·37	15·62	20·75	27·00	34·37	42·87	52·75	64·00	76·75	91·12	7
7·5	·81	1·62	2·81	4·32	6·64	9·44	12·94	17·30	22·50	28·63	35·80	43·86	53·40	64·00	76·02	7·5
8	·62	1·25	2·25	3·37	5·37	7·62	10·37	13·87	18·12	23·00	28·75	35·00	42·87	51·37	61·00	8
8·5	·53	1·06	1·92	2·90	4·39	6·45	8·83	11·82	15·36	19·49	24·43	29·63	36·33	43·69	51·59	8·5
9	·44	·89	1·59	2·52	3·44	5·37	7·37	9·78	12·70	16·15	20·19	24·81	30·11	36·11	43·00	9
9·5	·38	·76	1·32	2·12	3·08	4·40	6·00	8·02	10·41	13·24	16·53	19·34	24·67	29·58	35·17	9·5
10	·34	·66	1·16	1·84	2·75	3·91	5·31	7·14	9·26	11·78	14·70	17·05	21·95	26·32	31·25	10
10·5	·296	·593	1·00	1·59	2·37	3·37	4·63	6·15	8·00	10·19	12·70	15·63	18·96	22·74	28·78	10·5
11	·258	·504	·870	1·38	2·06	2·94	4·03	5·36	6·96	8·85	11·05	13·59	16·50	19·78	26·32	11
11·5	·208	·429	·738	1·17	1·75	2·49	3·41	4·53	5·89	7·49	9·36	11·51	14·00	16·75	23·86	11·5
12	·188	·391	·672	1·06	1·59	2·26	3·11	4·12	5·36	6·81	8·51	10·47	13·70	15·23	21·40	12
12·5	·167	·350	·604	·86	1·44	2·03	2·76	3·72	4·82	6·02	7·66	9·40	11·44	13·72	18·94	12·5
13	·147	·310	·537	·75	1·28	1·81	2·42	3·31	4·29	5·22	6·82	8·34	10·18	12·21	16·48	13
13·5	·127	·270	·470	·748	1·12	1·59	2·08	2·90	3·76	4·42	5·98	7·28	8·92	10·70	14·02	13·5
14	·118	·233	·427	·680	1·02	1·44	1·91	2·64	3·42	4·11	5·44	6·63	8·12	9·73	11·56	14
14·5	·110	·197	·385	·613	·91	1·30	1·74	2·38	3·08	3·80	4·90	5·97	7·31	8·76	10·41	14·5
15	·102	·161	·343	·546	·815	1·16	1·57	2·12	2·74	3·49	4·36	5·31	6·50	7·80	9·26	15
15·5	·085	·158	·302	·463	·719	1·02	1·39	1·86	2·42	3·18	3·85	4·69	5·74	6·86	8·17	15·5
16	·077	·156	·281	·421	·671	·952	1·30	1·73	2·26	2·87	3·59	4·38	5·36	6·42	7·62	16
16·5	·072	·149	·258	·409	·611	·870	1·19	1·59	2·06	2·62	3·27	4·03	4·89	5·86	6·96	16·5
17	·068	·135	·230	·366	·545	·775	1·06	1·42	1·84	2·34	2·92	3·60	4·36	5·23	6·21	17
17·5	·064	·128	·216	·344	·512	·728	1·00	1·33	1·73	2·20	2·74	3·38	4·10	4·91	5·83	17·5
18	·059	·118	·201	·322	·480	·678	·94	1·25	1·60	2·07	2·56	3·13	3·82	4·57	5·43	18
18·5	·055	·109	·187	·299	·446	·631	·87	1·16	1·49	1·92	2·38	2·88	3·55	4·25	5·05	18·5
19	·050	·100	·173	·276	·412	·584	·80	1·07	1·38	1·77	2·20	2·63	3·28	3·93	4·67	19
19·5	·046	·091	·159	·253	·378	·537	·73	·98	1·27	1·62	2·02	2·38	3·01	3·61	4·29	19·5
20	·042	·082	·145	·230	·344	·490	·664	·892	1·16	1·47	1·84	2·13	2·74	3·29	3·91	20
20·5	·040	·077	·137	·217	·325	·465	·628	·844	1·09	1·40	1·55	2·03	2·57	3·09	3·70	20·5
21	·038	·073	·130	·205	·307	·439	·594	·797	1·03	1·33	1·48	1·93	2·43	2·92	3·50	21
21·5	·035	·069	·122	·193	·289	·413	·560	·750	0·97	1·25	1·41	1·82	2·29	2·75	3·30	21·5
22	·032	·065	·114	·181	·271	·387	·526	·703	·091	1.17	1·34	1·72	2·15	2·58	3·09	22
22·5	·030	·061	·106	·169	·253	·361	·492	·656	·085	1·09	1·27	1·62	2·01	2·41	2·89	22·5
23	·028	·057	·099	·157	·235	·335	·458	·609	·079	1·01	1·20	1·51	1·87	2·24	2·68	23
23·5	·025	·053	·091	·144	·217	·309	·424	·562	·073	·93	1·13	1·41	1·73	2·07	2·47	23·5
24	·023	·049	·084	·132	·199	·283	·390	·515	·067	·851	1·06	1·31	1·59	1·90	2·27	24
24·5	·022	·045	·077	·123	·184	·260	·357	·477	·62	·787	·98	1·21	1·47	1·76	2·10	24·5
25	·022	·042	·074	·118	·176	·250	·340	·457	·593	·754	·941	1·15	1·40	1·68	2·00	25
25·5	·020	·040	·069	·112	·167	·236	·322	·435	·483	·715	·893	1·09	1·33	1·59	1·90	25·5
26	·019	·038	·065	·106	·158	·224	·306	·412	·473	·677	·846	1·03	1·26	1·51	1·80	26
26·5	·018	·036	·062	·100	·149	·212	·290	·389	·463	·640	·799	·974	1·19	1·43	1·70	26·5
27	·017	·034	·059	·094	·140	·200	.274	·366	·454	·603	·753	·921	1·12	1·35	1·60	27
27·5	·016	·032	·056	·088	·132	·188	·258	·343	·445	·566	·707	·870	1·05	1·27	1·50	27·5
28	·015	·030	·051	·084	·126	·178	·246	·327	·425	·540	·673	·834	·998	1·21	1·42	28
28·5	·014	·029	·048	·080	·120	·169	·234	·311	·404	·514	·641	·801	·940	1·15	1·35	28·5
29	·013	·027	·046	·076	·114	·161	·222	·295	·384	·488	·609	·768	·899	1·09	1·28	29
29·5	·012	·026	·044	·072	·108	·153	·210	·279	·363	·462	·577	·735	·856	1·03	1·22	29·5
30	·012	·025	·043	·068	·102	·145	·199	·264	·343	·436	·545	·702	·813	·975	1·16	30
30·5	·011	·023	·040	·064	·097	·138	·189	·253	·322	·417	·521	·664	·777	·931	1·10	30·5
31	·011	·021	·037	·060	·092	·131	·179	·242	·301	·398	·497	·626	·741	·887	1·05	31
31·5	·010	·020	·034	·056	·088	·125	·169	·231	·280	·379	·473	·588	·705	·843	·998	31·5
32	·010	·019	·032	·053	·084	·119	·160	·220	·260	·360	·450	·550	·670	·800	·950	32
32·5	·010	·019	·031	·052	·082	·116	·155	·210	·250	·350	·420	·530	·660	·780	·920	32·5
33	·010	·018	·031	·051	·080	·113	·150	·210	·250	·340	·430	·520	·650	·770	·900	33
33·5	·009	·018	·030	·049	·076	·108	·140	·190	·240	·330	·410	·490	·620	·730	·860	33·5
34	·009	·017	·029	·047	·072	·102	·140	·180	·230	·310	·380	·470	·590	·690	·820	34
34·5	·009	·017	·028	·045	·068	·096	·130	·170	·220	·290	·360	·440	·560	·650	·770	34·5
35	·008	·016	·027	·043	·064	·091	·125	·166	·216	·275	·343	·422	·544	·614	·729	35
35·5	·008	·015	·025	·041	·062	·088	·119	·160	·209	·266	·332	·405	·525	·593	·705	35·5
36	·007	·015	·023	·040	·060	·085	·113	·156	·202	·257	·319	·390	·505	·573	·680	36
36·5	·007	·014	·022	·039	·058	·082	·107	·150	·195	·248	·307	·374	·485	·553	·655	36·5
37	·007	·014	·021	·038	·056	·079	·103	·145	·188	·239	·296	·359	·465	·533	·630	37
37·5	·006	·013	·020	·037	·054	·076	·099	·139	·181	·230	·285	·343	·444	·512	·605	37·5
38	·006	·012	·020	·036	·051	·073	·096	·134	·173	·221	·274	·328	·424	·492	·580	38
38·5	·006	·012	·019	·034	·049	·070	·093	·128	·166	·211	·263	·312	·403	·472	·555	38·5
39	·005	·011	·018	·033	·047	·067	·089	·123	·159	·202	·252	·297	·382	·451	·530	39
39·5	·005	·010	·017	·032	·045	·064	·086	·117	·152	·193	·241	·281	·362	·431	·505	39·5
40	·005	·010	·016	·031	·043	·061	·083	·112	·145	·184	·230	·266	·342	·411	·480	40

CHAPTER VI.

EXPLANATION OF THE TABLES.

Having given these extensive tables, we now proceed to explain their use, to mention the formula from which they are derived, and to apply them to a particular example. The particular example which we shall select is that of an engine having 8 feet stroke and 64 inch cylinder.

Table at page 125.—This is a table for giving the breadth of the web of the crank at paddle centre; that is to say, the breadth which the web would have if it were continued to the paddle centre. Suppose that we wished the breadth of the web of crank of an engine whose stroke is 8 feet and diameter of cylinder 64 inches. Under the column marked 8, and in a line with 64, there stands the number 17·99. Hence, according to the table, the proper breadth of the web of crank at paddle centre would be about 18 inches.

This table is calculated from the following rule, which gives the proper breadth for an engine having any length of stroke and diameter of cylinder.

Rule.—*To find the breadth of crank at paddle centre. Multiply the square of the length of the crank in inches by* 1·561, *and then multiply the square of the diameter of cylinder in inches by* ·1235; *multiply the square root of the sum of these products by the square of the diameter of the cylinder in inches; divide the product by* 45; *finally extract the cube root of the quotient. The result is the breadth of the web of crank at paddle centre.*

Thus to apply this rule to the particular example which we have selected, we have

48 = length of crank in inches.
48
2304
1·561 = constant multiplier.
3596·5
505·8
4102·3

64 = diameter of cylinder.
64
4096
·1235 = constant multiplier.
505·8

and $\sqrt{4102·3}$ = 64·05 nearly.
4096 = square of the diameter of the cylinder.
45) 262348·5
5829·97

and $\sqrt[3]{5829·97}$ = 18 nearly.

Table at page 126.—This is a table for giving the proper thickness of the large eye of crank in inches. Suppose that we wished the proper thickness of the large eye of crank for an engine whose stroke is 8 feet and diameter of cylinder 64 inches. Under the column marked 8 and in a line with 64, there stands the number 5·77. Hence, according to the table, the proper thickness for the large eye of crank is about 5¾ inches.

This table is calculated from the following rule, which gives the proper thickness of eye for engines of any length of stroke and diameter of cylinder.

Rule.—*To find the thickness of large eye of crank. Multiply the square of the length of the crank in inches by* 1·561, *and then multiply the square of the diameter of the cylinder in inches by* ·1235; *multiply the sum of these products by the square of the diameter of the cylinder in inches; afterwards, divide the product by* 1828·28; *divide this quotient by the length of the crank in inches; finally extract the cube root of the quotient. The result is the proper thickness of the large eye of crank in inches.*

Thus to apply this rule to the particular example which we have selected, we have

48 = length of crank in inches.
48
2304
1·561 = constant multiplier.
3596·5
505·8
4102·3

64 = diameter of cylinder in inches.
64
4096
·1235 = constant multiplier.
505·8

4102·3
4096 = square of diameter.
48) 16803020·8
1828·28) 350062·94
191·47

and $\sqrt[3]{191·47}$ = 5·77 nearly.

Table in page 127.—This is a table for giving the proper thickness of the web of crank at paddle shaft centre; that is to say, the thickness which the web ought to have if continued to centre of the shaft. Suppose that it were required to find the proper thickness of web of crank at shaft centre for an engine whose stroke is 8 feet and diameter of cylinder 64 inches. Under the column marked 8, and in a line with 64, there stands the number 8·97. Hence, according to the rule, the proper thickness of the web at shaft centre would be about 9 inches.

This table is calculated from the following rule, which gives the proper thickness for all sizes of engines.

Rule.—*To find the thickness of the web of crank at paddle shaft centre. Multiply the square of the length of crank in inches by* 1·561, *and then multiply the square of the diameter in inches by* ·1235; *multiply the square root of the sum of these products by the square of the diameter of the cylinder in inches; divide this quotient by* 360; *finally extract the cube root of the quotient. The result is the thickness of the web of crank at paddle shaft centre in inches.*

Thus to apply the rule to the particular example which we have selected, we have

48 = length of crank in inches.
48
2304
1·561 = constant multiplier.
3596·5
505·8
4102·3

64 = diameter of cylinder.
64
4096
·1235 = constant multiplier.
505·8

And $\sqrt{4102{\cdot}3} = 64{\cdot}05$ nearly
4096 = square of diameter
360) 262348·5
728·75

And $\sqrt[3]{728{\cdot}75} = 9$ nearly.

Table in page 128.—This is a table for finding the proper diameter of the paddle shaft journal. Suppose that it were required to find the proper diameter for the paddle shaft journal of an engine whose stroke is 8 feet and diameter of cylinder 64 inches. In the column which is headed 8, and in a line with 64, there stands the number 14·06. Hence, according to the rule, the proper diameter of the paddle shaft journal is 14 inches.

This table is calculated from the following rule, which gives the proper diameter of the journal for engines of all sizes.

Rule.—*To find the diameter of the paddle shaft journal.—Multiply the square of the diameter of cylinder in inches by the length of the crank in inches; extract the cube root of the product; finally, multiply the result by* ·242. *The final product is the diameter of the paddle shaft journal in inches.*

Thus, to apply this rule to the particular example which we have selected, we have

64 = diameter of cylinder inches.
64
4096
48 = length of crank in inches.
196608

and $\sqrt[3]{196608} = 58{\cdot}148$
but $58{\cdot}148 \times {\cdot}242 = 14{\cdot}07$ inches.

Table in page 129. This is a table for determining the length of the paddle shaft journal. Suppose it were required to find the proper length of the paddle shaft journal for an engine whose stroke is 8 feet, and diameter of cylinder 64 inches. In the column headed 8, and in a line with 64, there stands the number 17·59. Hence, according to the table, the proper length of the paddle shaft journal would be about 17½ inches.

This table is calculated from the following rule, which serves for engines of all sizes.

Rule.—*To find the length of the paddle shaft journal.—Multiply the square of the diameter of the cylinder in inches by the length of the crank in inches; extract the cube root of the quotient; multiply the result by* ·303. *The product is the length of the paddle shaft journal in inches.* (*The length of the paddle shaft journal is* 1¼ *times the diameter.*)

To apply this rule to the example which we have selected, we have

64 = diameter of cylinder in inches.
64
4096
48 = length of crank in inches.
196608

and $\sqrt[3]{196608} = 58{\cdot}148$
$\therefore$ length of journal $= 58{\cdot}148 \times {\cdot}303 = 17{\cdot}60$ inches.

Tables in pages 130. and 131.—These tables give the proper dimensions of some of those parts which do not depend upon the length of the stroke. Suppose it were required to find the proper dimensions of the respective parts of a marine engine the diameter of whose cylinder is 64 inches. Here, in a line with 64, we find successively,

Diameter of crank-pin journal = 90·9 inches, or about 9 inches.

Length of crank-pin journal = 10·18 inches, or nearly 10¼ inches.

Breadth of the eye of cross-head = 2·64 inches, or between 2½ and 2¾ inches.

Depth of the eye of cross-head = 18·37 inches, or very nearly 18½ inches.

Diameter of the journal of cross-head = 5·5 inches, or 5½ inches.

Length of journal of cross-head = 6·19 inches, or very nearly 6¼ inches.

Thickness of the web of cross-head at middle = 4·6 inches, or somewhat more than 4½ inches.

Breadth of web of cross-head at middle = 17·15 inches, or between 17$\frac{1}{16}$ and 17¼ inches.

Thickness of web of cross-head at journal = 3·93 inches, or very nearly 4 inches.

Breadth of web of cross-head at journal = 6·46 inches, or nearly 6½ inches.

Diameter of piston rod = 6·4 inches, or 6⅜ inches.

Length of part of piston rod in piston = 12·8 inches, or 12¾ inches.

Major diameter of part of piston rod in cross-head = 06·8 inches, or nearly 6$\frac{1}{16}$ inches.

Minor diameter of part of piston rod in cross-head = 5·76 inches, or 5¾ inches.

Major diameter of part of piston rod in piston = 8·96 inches, or nearly 9 inches.

Minor diameter of part of piston rod in piston = 7·36 inches, or between 7¼ and 7½ inches.

Depth of gibs and cutter through cross-head = 6·72 inches, or very nearly 6¾ inches.

Thickness of gibs and cutter through cross-head = 1·35 inches, or between 1¼ and 1½ inches.

Depth of cutter through piston = 5·45 inches, or nearly 5½ inches.

Thickness of cutter through piston = 2·24 inches, or nearly 2¼ inches.

Diameter of connecting rod at ends = 6·08 inches, or nearly 6$\frac{1}{16}$ inches.

Major diameter of part of connecting rod in cross-tail = 6·27 inches, or about 6¼ inches.

Minor diameter of part of connecting rod in cross-tail = 5·76 inches, or nearly 5¾ inches.

Breadth of butt = 9·98 inches, or very nearly 10 inches.

Thickness of butt = 8 inches.

Mean thickness of strap at cutter = 2·75 inches, or 2¾ inches.

Mean thickness of strap above cutter = 2·06 inches, or somewhat more than 2 inches.

Distance of cutter from end of strap = 3·08 inches, or very nearly 3$\frac{1}{16}$ inches.

Breadth of gibs and cutter through cross-tail = 6·73 inches, or very nearly 6¾ inches.

Breadth of gibs and cutter through butt = 7·04 inches, or somewhat more than 7 inches.

Thickness of gibs and cutter through butt = 1·84 inches, or between 1¾ and 2 inches.

These tables are calculated from the following rules, which give correct results for all sizes of engines.

Rule 1.—*To find the diameter of crank-pin journal.—Multiply the diameter of the cylinder in inches by* ·142. *The result is the diameter of crank-pin journal in inches.*

Rule 2.—*To find the length of crank-pin journal.—Multiply the diameter of the cylinder in inches by* ·16. *The product is the length of the crank-pin journal in inches.*

Rule 3.—*To find the breadth of the eye of cross-head.—Multiply the diameter of the cylinder in inches by* ·041. *The product is the breadth of the eye in inches.*

Rule 4.—*To find the depth of the eye of cross-head.—Multiply the diameter of the cylinder in inches by* ·286. *The product is the depth of the eye of cross-head in inches.*

Rule 5.—*To find the diameter of the journal of cross-head.—Multiply the diameter of the cylinder in inches by* ·086. *The product is the diameter of the journal in inches.*

Rule 6.—*To find the length of the journal of cross-head.—Multiply the diameter of the cylinder in inches by* ·097. *The product is the length of the journal in inches.*

Rule 7.—*To find the thickness of the web of cross-head at middle.—Multiply the diameter of the cylinder in inches by* ·072. *The product is the thickness of the web of cross-head at middle in inches.*

Rule 8.—*To find the breadth of web of cross-head at middle.—Multiply the diameter of the cylinder in inches by* ·268. *The product is the breadth of the web of cross-head at middle in inches.*

Rule 9.—*To find the thickness of the web of cross-head at journal.—Multiply the diameter of the cylinder in inches by* ·061. *The product is the thickness of the web of cross head at journal in inches.*

Rule 10.—*To find the breadth of web of cross-head at journal.—Multiply the diameter of the cylinder in inches by* ·101. *The product is the breadth of the web of cross-head at journal in inches.*

Rule 11.—*To find the diameter of the piston rod.—Divide the diameter of the cylinder in inches by* 10. *The quotient is the diameter of the piston rod in inches.*

Rule 12.—*To find the length of the part of the piston rod in the piston.—Divide the diameter of the cylinder in inches by* 5. *The quotient is the length of the part of the piston rod in the piston in inches.*

Rule 13.—*To find the major diameter of the part of piston rod in cross-head.—Multiply the diameter of the cylinder in inches by* ·095. *The product is the major diameter of the part of piston rod in cross-head in inches.*

Rule 14.—*To find the minor diameter of the part of piston rod in cross-head.—Multiply the diameter of the cylinder in inches by* ·09. *The product is the minor diameter of the part of piston rod in cross-head in inches.*

Rule 15.—*To find the major diameter of the part of piston rod in piston.—Multiply the diameter of the cylinder in inches by* ·14. *The product is the major diameter of the part of the piston rod in piston in inches.*

Rule 16.—*To find the minor diameter of the part of piston rod in piston.—Multiply the diameter of the cylinder in inches by* ·115. *The product is the minor diameter of the part of piston rod in piston.*

Rule 17.—*To find the depth of gibs and cutter through cross-head.—Multiply the diameter of the cylinder in inches, by* ·105. *The product is the depth of the gibs and cutter through cross-head.*

Rule 18.—*To find the thickness of the gibs and cutter through cross-head.—Multiply the diameter of the cylinder in inches, by* ·021. *The product is the thickness of the gibs and cutter through cross-head.*

Rule 19. — *To find the depth of cutter through piston. — Multiply the diameter of the cylinder in inches by ·085. The product is the depth of the cutter through piston in inches.*

Rule 20. — *To find the thickness of cutter through piston. — Multiply the diameter of the cylinder in inches by ·035. The product is the thickness of cutter through piston in inches.*

Rule 21. — *To find the diameter of connecting rod at ends. — Multiply the diameter of the cylinder in inches by ·095. The product is the diameter of the connecting rod at ends in inches.*

Rule 22. — *To find the major diameter of the part of connecting rod in cross-tail. — Multiply the diameter of the cylinder in inches by ·098. The product is the major diameter of the part of connecting rod in cross-tail.*

Rule 23. — *To find the minor diameter of the part of connecting rod in cross-tail. — Multiply the diameter of the cylinder in inches by ·09. The product is the minor diameter of the part of connecting rod in cross-tail in inches.*

Rule 24. — *To find the breadth of butt. — Multiply the diameter of the cylinder in inches by ·156. The product is the breadth of the butt in inches.*

Rule 25. — *To find the thickness of the butt. — Divide the diameter of the cylinder in inches by 8. The quotient is the thickness of the butt in inches.*

Rule 26. — *To find the mean thickness of the strap at cutter. — Multiply the diameter of the cylinder in inches by ·043. The product is the mean thickness of the strap at cutter.*

Rule 27. — *To find the mean thickness of the strap above cutter. — Multiply the diameter of the cylinder in inches by ·032. The product is the mean thickness of the strap above cutter.*

Rule 28. — *To find the distance of cutter from end of strap. — Multiply the diameter of the cylinder in inches by ·048. The product is the distance of cutter from end of strap in inches.*

Rule 29. — *To find the breadth of the gibs and cutter through cross-tail. — Multiply the diameter of the cylinder in inches by ·105. The product is the breadth of the gibs and cutter through cross-tail.*

Rule 30. — *To find the breadth of the gibs and cutter through butt. — Multiply the diameter of the cylinder in inches by ·11. The product is the breadth of the gibs and cutter through butt in inches.*

Rule 31. — *To find the thickness of the gibs and cutter through butt. — Multiply the diameter of the cylinder in inches by ·029. The product is the thickness of the gibs and cutter through butt in inches.*

Table in page 132. — The first four columns of this table are some parts of the engine which do not depend upon the stroke. Suppose it were required to find the thickness of the small eye of crank for an engine the diameter of whose cylinder is 64 inches. Here, in the column headed *Breadth of Small Eye of Crank*, and in a line with 64, there stands the number 4·04. Hence, according to the table, the proper thickness of the small eye of crank is about 4 inches. Again, suppose it were required to find the length of the small eye of crank. In the column headed *Length of Ditto*, and in a line with 64, there stands the number 11·94. Hence, according to the table, the proper length of the small eye of crank is nearly 12 inches. Again, supposing it were required to find the proper thickness of the web of crank at pin centre; that is to say, the thickness which it would have if continued to the pin centre. In the column headed *Thickness of Web of Crank at Pin Centre*, and in a line with 64, there stands the number 7·04. Hence, according to the table, the proper thickness for the web of crank at pin centre is about 7 inches. Again, suppose it were required to find the breadth of the web of crank at pin centre; that is to say, the breadth which it would have if it were continued to the pin centre. In the column headed *Breadth of Ditto*, and in a line with 64, there stands the number 10·24. Hence, according to the table, the proper breadth for the web of crank at pin centre is about $10\frac{1}{4}$ inches.

These four columns are calculated from the following rules, which give the proper dimensions for engines of all sizes.

Rule 1. — *To find the breadth of the small eye of crank. — Multiply the diameter of the cylinder in inches by ·063. The product is the proper breadth of the small eye of crank in inches.*

Rule 2. — *To find the length of the small eye of crank. — Multiply the diameter of the cylinder in inches by ·187. The product is the proper length of the small eye of crank in inches.*

Rule 3. — *To find the thickness of the web of crank at pin centre. — Multiply the diameter of the cylinder in inches by ·11. The product is the proper thickness of the web of crank at pin centre in inches.*

Rule 4. — *To find the breadth of the web of crank at pin centre. — Multiply the diameter of the cylinder in inches by ·16. The product is the proper breadth of crank at pin centre in inches.*

The other columns in this page are useful for determining the proper diameters of the connecting rod and side rod at middle from the corresponding diameters at ends. To illustrate the use of these columns, let us take the particular example of an engine of 8 feet stroke and 64-inch cylinder, and let us suppose that the length of the connecting rod is 12 feet, and the side rod 10 feet. Referring back to page 131., we find that the diameter of the connecting rod at ends is 6·08, and the ratio between the diameters at middle and ends of a connecting rod, whose length is 12 feet, is 1·504. Hence, the proper diameter at middle of the connecting rod = 6·08 × 1·504 inches = 9·144 inches. Again, referring to page 133., we find the diameter of cylinder side rods at ends, for the particular engine which we have selected, is 4·10, and the ratio between the diameters at middle and ends of cylinder side rods, whose lengths are 10 feet, is 1·42. Hence, according to the tables, the proper diameter of the cylinder side rods at middle is equal to 4·1 × 1·42 inches = 5·82 inches.

Table in page 133. — This table gives the dimensions of some of those parts of the engine which do not depend upon the stroke. Suppose we take the particular example of an engine the diameter of whose cylinder is 64 inches. We find from the table, in a line with 64, that

Diameter of cylinder side rods at ends = 4·1 inches, or $4\frac{1}{10}$ inches.
Breadth of butt = 4·93 inches, or very nearly 5 inches.
Thickness of butt = 3·9 inches, or $3\frac{9}{10}$ inches.
Mean thickness of strap at cutter = 2·06 inches, or a little more than 2 inches.
Mean thickness of strap below cutter = 1·47 inches, or very nearly $1\frac{1}{2}$ inches.
Depth of gibs and cutter = 5·12 inches, or a little more than $5\frac{1}{10}$ inches.
Thickness of gibs and cutter = 1·03 inches, or a little more than 1 inch.
Diameter of main centre journal = 11·71 inches, or very nearly $11\frac{3}{4}$ inches.
Length of main centre journal = 17·6 inches, or $17\frac{3}{5}$ inches.
Depth of eye round end studs of lever = 4·75 inches, or $4\frac{3}{4}$ inches.
Thickness of eye round end studs of lever = 3·33 inches, or $3\frac{1}{3}$ inches.
Diameter of end studs of lever = 4·48 inches, or very nearly $4\frac{1}{2}$ inches.
Length of end studs of lever = 4·86 inches, or between $4\frac{3}{4}$ and 5 inches.
Diameter of air-pump studs = 2·91 inches, or nearly 3 inches.
Length of air-pump studs = 3·16 inches, or nearly $3\frac{1}{5}$ inches.

This table is calculated from the following rules, which will be found to give the proper dimensions for all sizes of engines.

Rule 1. — *To find the diameter of cylinder side rods at ends. — Multiply the diameter of the cylinder in inches by ·065. The product is the diameter of the cylinder side rods at ends in inches.*

Rule 2. — *To find the breadth of butt in inches. — Multiply the diameter of the cylinder in inches by ·077. The product is the breadth of the butt in inches.*

Rule 3. — *To find the thickness of the butt. — Multiply the diameter of the cylinder in inches by ·061. The product is the thickness of the butt in inches.*

Rule 4. — *To find the mean thickness of strap at cutter. — Multiply the diameter of the cylinder in inches by ·032. The product is the mean thickness of the strap at cutter,*

Rule 5. — *To find the mean thickness of strap below cutter. — Multiply the diameter of the cylinder in inches by ·023. The product is the mean thickness of strap below cutter in inches.*

Rule 6. — *To find the depth of gibs and cutter. — Multiply the diameter of the cylinder in inches by ·08. The product is the depth of gibs and cutter in inches.*

Rule 7. — *To find the thickness of gibs and cutter. — Multiply the diameter of the cylinder in inches by ·016. The product is the thickness of the gibs and cutter in inches.*

Rule 8. — *To find the diameter of the main centre journal. — Multiply the diameter of the cylinder in inches by ·183. The product is the diameter of the main centre journal in inches.*

Rule 9. — *To find the length of the main centre journal. — Multiply the diameter of the cylinder in inches by ·275. The product is the diameter of the cylinder in inches.*

Rule 10. — *To find the depth of eye round end studs of lever. — Multiply the diameter of the cylinder in inches by ·074. The product is the depth of the eye round end studs of lever in inches.*

Rule 11. — *To find the thickness of eye round end studs of lever. — Multiply the diameter of the cylinder in inches by ·052. The product is the thickness of eye round end studs of lever in inches.*

Rule 12. — *To find the diameter of the end studs of lever. — Multiply the diameter of the cylinder in inches by ·07. The product is the diameter of the end studs of lever in inches.*

Rule 13. — *To find the length of the end studs of lever. — Multiply the diameter of the cylinder in inches by ·076. The product is the length of the end studs of lever in inches.*

Rule 14. — *To find the diameter of the air-pump studs. — Multiply the diameter of the cylinder in inches by ·045. The product is the diameter of the air-pump studs in inches.*

Rule 15. — *To find the length of the air-pump studs. — Multiply the diameter of the cylinder in inches by ·049. The product is the length of the air-pump studs in inches.*

Table in page 134.—This table gives the proper depth in inches across the centre of the side lever, when, as is generally the case, the side lever is of cast iron. It will be observed that the depth is made to depend upon the diameter of the cylinder and the length of the lever, and not at all upon the length of the stroke, except indeed in so far as the length of the lever may depend upon the length of the stroke. Suppose it were required to find the proper depth across the centre of a side lever whose length is 20 feet, and the diameter of the cylinder 64 inches. In the column headed 20, and in a line with 64, there stands the number 39·26. Hence, according to the table, the proper depth across the centre would be about 39¼ inches.

This table is calculated from the following rule, which will give the proper dimensions for any size of engine.

Rule.—*To find the depth across the centre of the side lever.—Multiply the length of the side lever in feet by ·7423; extract the cube root of the product, and reserve the result for a multiplier. Then square the diameter of the cylinder in inches; extract the cube root of the result. The product of the final result and the reserved multiplier is the depth of the side lever in inches across the centre.*

Thus to apply this rule to the particular example which we have selected, we have,

20 = length of side lever in feet.
·7423 = constant multiplier.
14·846
and $\sqrt[3]{14{\cdot}846} = 2{\cdot}458$ nearly.
64 = diameter of cylinder in inches.
64
4096
and $\sqrt[3]{4096} = 16$

Hence depth at centre = 16 × 2·458 inches = 39·33 inches, or between 39¼ and 39½ inches.

Table in page 135.—This table gives the dimensions of several of the parts of the air-pump machinery which depend upon the diameter of the cylinder only. To illustrate the use of this table, let us take the particular example of an engine the diameter of whose cylinder is 64 inches. We find from the table successively,

Diameter of air-pump = 38·4 inches, or 38⅖ inches.

Thickness of the eye of air-pump cross-head = 1·58 inches, or a little more than 1½ inches.

Depth of eye of air-pump cross-head = 11·01, or about 11 inches.

Diameter of end journals of air-pump cross-head = 3·29 inches, or somewhat more than 3¼ inches.

Length of end journals of air-pump cross-head = 3·7 inches, or 3 7/10 inches.

Thickness of the web of air-pump cross-head at middle = 2·76 inches, or a little more than 2¾ inches.

Depth of web of air-pump cross-head at middle = 10·29 inches, or somewhat more than 10¼ inches.

Thickness of web of air-pump cross-head at journal = 2·35 inches, or about 2⅜ inches.

Depth of web of air-pump cross-head at journal = 3·89 inches, or about 3⅞ inches.

Diameter of air-pump piston rod when made of copper = 4·27 inches, or about 4¼ inches.

Depth of gibs and cutter through air-pump cross-head = 4·04 inches, or a little more than 4 inches.

Thickness of gibs and cutter through air-pump cross-head = ·81 inches, or about ⅘ inch.

Depth of cutter through piston = 3·27 inches, or somewhat more than 3¼ inches.

Thickness of cutter through piston = 1·34 inches, or about 1⅓ inches.

This table is calculated from the following rules, which give the proper dimensions for all sizes of engines:

Rule 1.—*To find the diameter of the air pump.—Multiply the diameter of the cylinder in inches by ·6. The product is the diameter of the air pump in inches.*

Rule 2.—*To find the thickness of the eye of air-pump cross-head.—Multiply the diameter of the cylinder in inches by ·025. The product is the thickness of the eye of air-pump cross-head in inches.*

Rule 3.—*To find the depth of eye of air-pump cross-head.—Multiply the diameter of the cylinder in inches by ·171. The product is the depth of the eye of air-pump cross-head in inches.*

Rule 4.—*To find the diameter of the journals of air-pump cross-head.—Multiply the diameter of the cylinder in inches by ·051. The product is the diameter of the end journals.*

Rule 5.—*To find the length of the end journals for air-pump cross-head.—Multiply the diameter of the cylinder in inches by ·058. The product is the length of the air-pump cross-head journals in inches.*

Rule 6.—*To find the thickness of the web of air-pump cross-head at middle.—Multiply the diameter of the cylinder in inches by ·043. The product is the thickness at middle of the web of air-pump cross-head in inches.*

Rule 7.—*To find the depth at middle of the web of air-pump cross-head.—Multiply the diameter of the cylinder in inches by ·161. The product is the depth at middle of air-pump cross-head in inches.*

Rule 8.—*To find the thickness of the web of air-pump cross-head at journals. Multiply the diameter of the cylinder in inches by ·037. The product is the thickness of the web of air-pump cross-head at journals in inches.*

Rule 9.—*To find the depth of the air-pump cross-head web at journals. Multiply the diameter of the cylinder in inches by ·061. The product is the depth at journals of the web of air-pump cross-head.*

Rule 10.—*To find the diameter of the air-pump piston rod when of copper.—Multiply the diameter of the cylinder in inches by ·067. The product is the diameter of the air-pump piston rod, when of copper, in inches.*

Rule 11.—*To find the depth of gibs and cutter through air-pump cross-head.—Multiply the diameter of the cylinder in inches by ·063. The product is the depth of the gibs and cutter through air-pump cross-head in inches.*

Rule 12.—*To find the thickness of the gibs and cutter through air-pump cross-head.—Multiply the diameter of the cylinder in inches by ·013. The product is the thickness of the gibs and cutter in inches.*

Rule 13.—*To find the depth of cutter through piston.—Multiply the diameter of the cylinder in inches by ·051. The product is the depth of the cutter through piston in inches.*

Rule 14.—*To find the thickness of cutter through air-pump piston.—Multiply the diameter of the cylinder in inches by ·021. The product is the thickness of the cutter through air-pump piston.*

Table in page 136.—The first seven columns of this table give the dimensions of the remaining parts of the engine which do not depend upon the stroke. To exemplify their use, suppose it were required to find the corresponding dimensions for an engine the diameter of whose cylinder is 64 inches. In the column headed "Diameter of Air-pump Side Rods at Ends," and in a line with 64, there stands the number 2·48. Hence, according to the table, the proper diameter of the air-pump side rod would be about 2½ inches. Again, in the column headed "Breadth of Butt," and in a line with 64, there stands the number 2·95. Hence, according to the table, the proper breadth of butt is very nearly 3 inches. Again, in the column headed "Thickness of Butt," and in a line with 64, there stands the number 2·35. Hence, according to the table, the proper thickness of butt is between 2¼ and 2½ inches. Again, in the column headed "Mean Thickness of Strap at Cutter," and in a line with 64, there stands the number 1·24. Hence, according to the table, the mean thickness of strap at cutter ought to be about 1¼ inches. Again, in the column headed "Mean Thickness of Strap below Cutter," and in a line with 64, there stands the number ·91. Hence, according to the table, the mean thickness of strap below cutter is about 9/10 of an inch. In the column headed "Depth of Gibs and Cutter," and in a line with 64, there stands the number 2·94. Hence, according to the table, the proper depth for the gibs and cutter is very nearly 3 inches. Finally, in the column headed "Thickness of Gibs and Cutter," and in a line with 64, there stands the number ·63. Hence, according to the table, the proper thickness of the gibs and cutter is about ⅝ inch.

These columns are calculated from the following rules, which give the correct dimensions for all sizes of engines:

Rule 1.—*To find the diameter of air-pump side rod at ends.—Multiply the diameter of the cylinder in inches by ·039. The product is the diameter of the air-pump side rod at ends in inches.*

Rule 2.—*To find the breadth of butt for air-pump.—Multiply the diameter of the cylinder in inches by ·046. The product is the breadth of butt in inches.*

Rule 3.—*To find the thickness of butt for air-pump.—Multiply the diameter of the cylinder in inches by ·037. The product is the thickness of butt for air-pump in inches.*

Rule 4.—*To find the mean thickness of strap at cutter.—Multiply the diameter of the cylinder in inches by ·019. The product is the mean thickness of strap at cutter for air-pump in inches.*

Rule 5.—*To find the mean thickness of strap below cutter.—Multiply the diameter of the cylinder in inches by ·014. The product is the mean thickness of strap below cutter in inches.*

Rule 6.—*To find the depth of gibs and cutter for air-pump.—Multiply the diameter of the cylinder in inches by ·048. The product is the depth of gibs and cutter for air-pump in inches.*

Rule 7.—*To find the thickness of gibs and cutter for air-pump.—Divide the diameter of the cylinder in inches by 100. The quotient is the proper thickness of the gibs and cutter for air-pump in inches.*

With regard to the other columns of this page, they are made to depend upon the nominal horse power of the engine. Suppose that we take the particular example of an engine whose stroke is 8 feet, and diameter of cylinder 64 inches. Referring back to the table given in pages 96 and 97, we find that the nominal horse power of this engine is nearly 175. Hence we find from the table successively,

Diameter of valve shaft at journal in inches = 4·85, or between 4⅞ and 5 inches.

Diameter of parallel motion shaft at journal in inches = 3·91, or very nearly 4 inches.

Diameter of valve rod in inches = 2·44, or about 2⅜ inches.

Diameter of radius rod at smallest part in inches = 1·97, or very nearly 2 inches.

Area of eccentric rod, at smallest part, in square inches = 8·37, or about 8⅜ square inches.

Sectional area of eccentric hoop in square inches = 8·75, or 8¾ square inches.

Diameter of eccentric pin in inches = 2·24, or 2¼ inches.

Breadth of valve lever for eccentric pin at eye in inches = 5·7, or very nearly 5¾ inches.

Thickness of valve lever for eccentric pin at eye in inches = 3.

Breadth of parallel motion crank at eye = 4·2 inches, or very nearly 4¼ inches.

Thickness of parallel motion crank at eye = 1·76 inches, or about 1¾ inches.

Table in page 137. — This table gives the area in square inches of each steam port. Suppose it were required to find the area of each steam port for an engine whose stroke is 8 feet, and diameter of cylinder 64 inches. In the column headed 8, and in a line with 64, there stands the number 202·26. Hence, according to the table, the area of each steam port would be about 202¼ square inches.

With regard to the rule from which this table is calculated, we may remark that the area of the steam port ought to depend principally upon the cubical content of the cylinder, which again depends entirely upon the product of the square of the diameter of the cylinder and the length of the stroke of the engine. It is well known, however, that the quantity of steam admitted by a small hole does not bear so great a proportion to the quantity admitted by a larger one, as the area of the one does to the area of the other; and a certain allowance ought to be made for this. In the absence of correct theoretical information on this point, we have attempted to make a proper allowance by supplying a constant; but of course this plan ought only to be regarded as an approximation. Our rule is as follows:

Rule. — *To find the area of each steam port. — Multiply the square of the diameter of the cylinder in inches by the length of the stroke in feet; multiply this product by* 11; *divide the last product by* 1800; *and, finally, to the quotient add* 8. *The result is the area of each steam port in square inches.*

To show the use of this rule, we shall apply it to a particular example. We shall apply it to an engine whose stroke is 6 feet, and diameter of cylinder 30 inches. Then, according to the rule, we have

30 = diameter of the cylinder in inches.
30
900 = square of diameter.
6 = length of stroke in feet.
5400
11
59400 ÷ 1800 = 33
8 = constant to be added.
41 = area of steam port in square inches;

which agrees with the area given in the tables.

When the length of the opening of steam port is from any circumstance found, the corresponding depth in inches may be found, by dividing the number given in the table, as corresponding to the particular engine, by the given length in inches: conversely, the length may be found, when for some reason or other the depth is fixed, by dividing the number given in the table, as corresponding to the particular engine, by the given depth in inches: the quotient is the length in inches.

Table in page 138.—This table is useful for determining the diameter of the steam pipe branching off to any particular engine. Suppose it were required to find the diameter of the branch steam pipe for an engine whose stroke is 8 feet, and diameter of cylinder 64 inches. In the column headed 8, and in a line with 64, there stands the number 13·15. Hence, according to the table, the proper diameter of the steam pipe would be between 13 and 13¼ inches.

With regard to the rule from which the table is calculated, we would make the same remarks as those we have made upon the rule for calculating the table in page 137. The following rule will be found to give the proper diameter of steam-pipe for all sizes of engines.

Rule. — *To find the diameter of branch steam pipe. — Multiply together the square of the diameter of the cylinder in inches, the length of the stroke in feet, and* ·00498; *to the product add* 10·2, *and extract the square root of the sum. The result is the diameter of the steam pipe in inches.*

To exemplify the use of this rule we shall take an engine whose stroke is 8 feet, and diameter of cylinder 64 inches. In this case we have as follows:—

64 = diameter of cylinder in inches.
64
4096 = square of diameter.
8 = length of stroke in feet.
32768
·00498 = constant multiplier.
163·18
10·2 = constant to be added.
173·38
and $\sqrt{173·38} = 13·16$,

which agrees very closely with the number given in the table.

Table in page 139.—This table gives the diameter of several of the pipes connected with the engine. They are made to depend upon the nominal horse power of the engine. Suppose it were required to apply this table to determine the size of the pipes for two marine engines, whose strokes are each 8 feet, and diameters of cylinder each 64 inches. Referring to the table of nominal horse power in pages 96 and 97, we find the nominal horse power of each of these engines to be 174·3, or nearly 175 horse power. Hence, according to the table, we have in succession,

Diameter of waste water pipe = 15·87 inches, or between 15⅞ and 16 inches.

Area of foot-valve passage = 323 square inches.

Area of injection pipe = 14·88 square inches.

If the injection pipe be cylindrical, then by referring to the table in page 24, we see that its diameter would be about 4⅜ inches.

Diameter of feed pipe = 4·12 inches, or between 4 and 4¼ inches.

Diameter of waste steam pipe = 12·17 inches, or nearly 12¼ inches.

Diameter of safety valve,

When one is used = 14·05 inches.
When two are used = 9·94 inches.
When three are used = 8·12 inches.
When four are used = 7·04 inches.

These columns are calculated from the following rules, which will give the correct dimensions for all sizes of engines.

Rule 1. — *To find the diameter of waste water pipe. — Multiply the square root of the nominal horse power of the engine by* 1·2. *The product is the diameter of the waste water pipe in inches.*

Rule 2. — *To find the area of foot-valve passage. — Multiply the nominal horse power of the engine by* 9; *divide the product by* 5; *add* 8 *to the quotient. The sum is the area of foot-valve passage in square inches.*

Rule 3. — *To find the area of injection pipe. — Multiply the nominal horse power of the engine by* ·069; *to the product add* 2·81. *The sum is the area of the injection pipe in square inches.*

Rule 4. — *To find the diameter of feed pipe. — Multiply the nominal horse power of the engine by* ·04; *to the product add* 3; *extract the square root of the sum. The result is the diameter of the feed pipe in inches.*

Rule 5. — *To find the diameter of waste steam pipe. — Multiply the collective nominal horse power of the engines by* ·375; *to the product add* 16·875; *extract the square root of the sum. The final result is the diameter of the waste steam pipe in inches.*

Rule 6. — *To find the diameter of the safety valve when only one is used. To one half the collective nominal horse power of the engines add* 22·5; *extract the square root of the sum. The result is the diameter of the safety valve when only one is used.*

Rule 7.—*To find the diameter of the safety valve when two are used.—Multiply the collective nominal horse power of the engines by* ·25; *to the product add* 11·25; *extract the square root of the sum. The result is the diameter of the safety valve when two are used.*

Rule 8. — *To find the diameter of the safety valve when three are used: — To one sixth of the collective nominal horse power of the engines add* 7·5; *extract the square root of the sum. The result is the diameter of the safety valve where three are used.*

Rule 9. — *To find the diameter of the safety valve when four are used. — Multiply the collective nominal horse power of the engines by* ·125; *to the product add* 5·625; *extract the square root of the sum. The result is the diameter of the safety valve when four are used.*

Another rule for safety-valves, and a preferable one for low pressures, is to allow ·8 of a circular inch of area per nominal horse power, as mentioned at page 198.

Table in page 140.—This is for determining the depth across the web of the main beam of a land engine. Suppose we wished to find the proper depth at the centre of the main beam of a land engine whose main beam is 16 feet long, and diameter of cylinder 64 inches. In the column headed

8, and in a line with 64, there stands the number 46·17. Hence, according to the table the proper depth of the web across the centre is between 46 and 46¼ inches. Referring back to the table in page 134, we find, in the column headed 16, and in a line with 64, the number 36·51; thus showing that the corresponding depth of a side lever is less by nearly 10 inches. The depth of the bead on edge of the beam varies in different engines, but the proportions of the example given at page 208 are commonly employed.

The table is calculated from the following rule, which gives correct dimensions for all sizes of engines.

Rule. — *To find the depth of the web at the centre of the main beam of a land engine.* — *Multiply together the square of the diameter of the cylinder in inches, half the length of the main beam in feet, and the number* 3; *extract the cube root of the product. The result is the proper depth of the web of the main beam across the centre in inches, when the main beam is constructed of cast iron.*

To illustrate this rule we shall take the particular example of an engine whose main beam is 20 feet long, and the diameter of the cylinder 64 inches. In this case we have.

```
        64 = diameter of cylinder in inches.
        64
      ----
      4096 = square of the diameter.
        10 = ½ length of main beam in feet.
     -----
     40960
         3 = constant multiplier.
    ------
    122880

   0          0        122880(49·714 = ∛122880
   4         16        64
  --        ---        -----
   4         16        58880
   4         32        53649
  --       ----        -----
   8       4800         5231
   4       1161         5112
 ---       ----         ----
 120       5961          119
   9       1242           74
 ---       ----          ---
 129       7203           35
   9         10
 ---        ---
 138        730
   9         10
 ---        ---
 147        741
```

Table in page 141. — This table is for determining the depth of the main beam across the ends. Suppose it were required to find the depth at ends of a cast-iron main beam whose length is 20 feet, when the diameter of the cylinder is 64 inches. In the column headed 10, and in a line with 64, there stands the number 19·85. Hence, according to the table, the proper depth would be between 19¾ and 20 inches.

This table is calculated from the following rule, which gives the proper dimensions for all sizes of engines.

Rule. — *To find the depth of main beam at ends.* — *Multiply together the square of the diameter of the cylinder in inches, half the length of the main beam in feet, and the number* ·192; *extract the cube root of the product. The result is the depth in inches of the main beam at ends, when of cast-iron.*

To illustrate this rule, let us apply it to the particular example of an engine whose main beam is 20 feet long, and the diameter of the cylinder 64 inches. In this case we have as follows:

```
        64 = diameter of cylinder in inches
        64
      ----
      4096 = square of diameter of cylinder.
        10 = ½ length of main beam in feet.
     -----
     40960
      ·192 = constant multiplier.
     -------
     7864·32

   0          0        7864·32(19·89 = ∛7864·32
   1          1        1
  --         --        ----
   1          1        6864
   1          2        5859
  --        ---        ----
   2        300        1005
   1        351         898
  --        ---        ----
  30        651         107
   9        432
  --       ----
  39       1083
   9          4
  --        ---
  48        112
   9          4
  --        ---
  57        116
```

so that, according to the rule, the depth at ends is nearly 20 inches.

Table in page 142. — This table gives the dimensions of the feed-pump in cubic inches. It may be useful for determining the diameter of the pump when its stroke is given; for, dividing the content of the feed-pump by the stroke of the pump in inches, the quotient is the area; and from this area the diameter may easily be found by reference to the table in pages 24 and 25. Conversely, the table may be useful for determining the stroke when the diameter of the pump is given; for dividing the number in this table corresponding to the given engine, by the area corresponding to the given diameter, which area may be found from the table in pages 24 and 25, the quotient is the stroke of the pump in inches. Suppose we take the particular example of an engine whose stroke is 8 feet, and diameter of cylinder 64 inches. The proper content of the feed-pump, according to the table, would be 1093·36 cubic inches. Suppose, now, that the cold-water pump was suspended from the main beam at a fourth of the distance between the centre and the end, so that its stroke would be 2 feet, or 24 inches. In this case the area of the pump would be equal to 1093·36 ÷ 24 = 45·556 square inches; so that we conclude, from the table in pages 24 and 25, that the diameter is between 7½ and 7¾ inches. Conversely, suppose that it was wished to find the stroke of the pump when the diameter was 5 inches. Referring to the table in pages 24 and 25, we find the area of the pump to be 19·635 square inches; so that the stroke of the feed-pump must be equal to 1093·36 ÷ 19·635 = 55·69 inches, or very nearly 55¾ inches.

This table is calculated from the following rule, which will be found to give correct dimensions for all sizes of engines:

Rule. — *To find the content of the feed-pump.* — *Multiply the square of the diameter of the cylinder in inches by the length of the stroke in feet; divide the product by* 30. *The quotient is the content of the feed-pump in cubic inches.*

Thus, for an engine whose stroke is 6 feet, and diameter of cylinder 50 inches, we have,

```
          50 = diameter of cylinder.
          50
        ----
        2500 = square of the diameter of the cylinder.
           6 = length of stroke in feet.
    ---------
    30)15000
    ---------
         500 = content of feed-pump in cubic inches.
```

Table in page 143. — This is a table for determining the content of the cold-water pump in cubic feet. It may be useful either for determining the diameter of the pump when its stroke is given, or, conversely, for determining the stroke of the pump when its diameter is given. To illustrate this, suppose we take the particular example of an engine whose stroke is 8 feet and diameter of cylinder 64 inches. In the column headed 8, and in a line with 64, there stands the number 7·45. Suppose, now, the stroke of the pump to be 5 feet, then the area equal to 7·45 + 5 = 1·49 square feet = 214·56 square inches; so that, referring to the table in pages 24 and 25, we see that the diameter of the pump is about 16½ inches. Again, suppose that the diameter of the cold-water pump was 20 inches, and that it was required to find the length of its stroke. We find, from the table in pages 24 and 25, that the area of the pump is 314·16 square inches, or 314·16 ÷ 144 = 2·18 square feet; so that the stroke of the pump is equal to 7·45 + 2·18 = 3·42 feet.

This table is calculated from the following rule, which will be found to give correct dimensions for all sizes of engines:

Rule. — *To find the content of the cold-water pump.* — *Multiply the square of the diameter of the cylinder in inches by the length of the stroke in feet; divide the product by* 4400. *The quotient is the content of the cold-water pump in cubic feet.*

To explain this rule we shall take the particular example of an engine whose stroke is 5½ feet, and diameter of cylinder 60 inches. In this case we have in succession,

```
            60 = diameter of cylinder in inches.
            60
          ----
          3600 = square of the diameter of cylinder.
            5½ = length of stroke in feet.
    -----------
    4400)19800
          ----
           4·5 = content of cold-water pump in cubic feet.
```

Some further remarks on the feed and cold-water pumps will be found at page 215.

Table in page 144.—This table is for determining the proper thickness of the large eye of crank for fly-wheel shaft when the crank is of cast iron. The crank is sometimes cast on the shaft, and of course the thickness of the large eye is not then so great as when the crank is only keyed on the shaft, or rather there is then no large eye at all. To illustrate the use of this table we shall apply it to the particular example of an engine whose stroke is 8 feet, and diameter of cylinder 64 inches. In the column headed 8, and in a line with 64, there stands the number 8·07. Hence, according to the table, the proper thickness of the large eye of crank when of cast iron is about 8 inches. Referring to the table in page 126, in the column headed 8, and in a line with 64, there stands the number 5·77: so that for a marine engine of 8 feet stroke, and 64 inch cylinder, the thickness of the large eye of crank is about 5¾ inches. The difference is thus about 2¼ inches, which is an allowance for the inferiority of cast iron to malleable iron.

This table is calculated from the following rule, which will be found to give correct dimensions for all sizes of engines:

Rule.—*To find the thickness of the large eye of crank for fly-wheel shaft when of cast iron.*—*Multiply the square of the length of the crank in inches by* 1·561, *and then multiply the square of the diameter of the cylinder in inches by* ·1235; *multiply the sum of these products by the square of the diameter of cylinder in inches; divide this product by* 666·283; *divide this quotient by the length of the crank in inches; finally extract the cube root of the quotient. The result is the proper thickness of the large eye of crank for fly-wheel shaft in inches, when of cast iron.*

As this rule is rather complicated, we shall show its application to the particular example already selected. For this particular example we have in succession,

48 = length of crank in inches.
48
2304 = square of length of crank in inches.
1·561 = constant multiplier.
3596·5
64 = diameter of cylinder in inches.
64
4096 = square of the diameter of cylinder.
·1235 = constant multiplier.
505·8
3596·5
4102·3 = sum of products.
4096 = square of the diameter of cylinder.
666·283) 16803020·8
length of crank = 48) 25219·045
525·397
and $\sqrt[3]{525\cdot397}$ = 8·07 nearly.

Table in page 145.—This is a table for determining the breadth of the web of crank at the centre of the fly-wheel shaft, that is to say, the breadth which it would have if it were continued to the centre of the fly-wheel shaft. Suppose it were required to find the breadth of the crank at the centre of the fly-wheel shaft for an engine whose stroke is 8 feet, and diameter of cylinder 64 inches. In the column headed 8, and in a line with 64, there stands the number 22·49. Hence, according to the table, the proper breadth is about 22½ inches. Referring to the table in page 125, in the column headed 8, and in a line with 64, there stands the number 17·99. Hence, according to that table, the breadth of the web of a cast-iron crank of an engine whose stroke is 8 feet, and diameter of cylinder 64 inches, is about 18 inches. The difference between these two is about 4½ inches; which is not too great an allowance for the inferiority of the cast iron.

This table is calculated from the following rule, which will be found to give correct dimensions for all sizes of engines:

Rule.—*To find the breadth of the web of crank at fly-wheel shaft, when of cast iron.*—*Multiply the square of the length of the crank in inches by* 1·561, *and then multiply the square of the diameter of the cylinder in inches by* ·1235; *multiply the square root of the sum of these products by the square of the diameter of the cylinder in inches; divide the product by* 23·04, *and finally extract the cube root of the quotient. The final result is the breadth of the crank at the centre of the fly-wheel shaft, when the crank is of cast iron.*

As this rule is rather complicated, we shall illustrate it by showing its application to the particular example of an engine whose stroke is 8 feet, and diameter of cylinder 64 inches. For this engine, following the directions of the rule, we have in succession,

64 = diameter of cylinder in inches.
64
4096 = square of the diameter of cylinder.
·1235 = constant multiplier.
505·8
48 = length of crank in inches.
48
2304 = square of the length of crank.
1·561 = constant multiplier.
3596·5
505·8
4102·3 = sum of products.
$\sqrt{4102\cdot3}$ = 64·05 nearly.
4096 = square of the diameter of cylinder.
constant divisor = 23·04) 262348·5
11386·66 nearly.
and $\sqrt[3]{11386\cdot66}$ = 22·49.

Table in page 146.—This is a table for determining the thickness of the web of crank at the centre of the fly-wheel shaft; that is to say, the thickness which it would have if it were continued so far. Suppose it were required to find the thickness of web of crank at the centre of fly-wheel shaft of an engine whose stroke is 8 feet, and diameter of cylinder 64 inches. In the column headed 8, and in a line with 64, there stands the number 11·26. Hence, according to the table, the proper thickness would be about 11¼ inches. Referring to the table in page 127, in the column headed 8, and in a line with 64, there stands the number 8·92. Hence, the proper thickness of web at centre of paddle shaft for a marine engine whose stroke is 8 feet, and diameter of cylinder 64 inches, is nearly 9 inches. The difference between the two thicknesses is about 2¼ inches, which is not too great an allowance for the inferiority of cast iron to malleable iron. This table is calculated from the following rule, which will be found to give correct dimensions for all sizes of engines:—

Rule.—*To find the thickness of the web of crank at centre of fly-wheel shaft, when of cast iron.*—*Multiply the square of the length of the crank in inches by* 1·561, *and then multiply the square of the diameter of the cylinder in inches by* ·1235; *multiply the square root of the sum of these products by the square of the diameter of the cylinder in inches; divide this product by* 184·32; *finally extract the cube root of the quotient. The result is the thickness of the web of crank at the centre of the fly-wheel shaft when of cast iron, in inches.*

As this rule is rather complicated, we shall illustrate it by applying it to the particular engine which we have already selected. For this engine we have in succession,

48 = length of crank in inches.
48
2304 = square of the length of crank.
1·561 = constant multiplier.
3596·5
64 = diameter of cylinder in inches.
64
4096 = square of the diameter of cylinder.
·1235 = constant multiplier.
505·8
3596·5
4102·3 = sum of products.
and $\sqrt{4102\cdot3}$ = 64·05 nearly.
4096 = square of diameter
Constant divisor = 184·32) 262348·5
1423·33
and $\sqrt[3]{1423\cdot33}$ = 11·25.

Table in page 147.—This is a table for determining the proper diameter of the fly-wheel shaft at its smallest part, when, as is usually the case, it is of cast iron. Suppose it was required to find the diameter of the fly-wheel shaft for an engine whose stroke is 8 feet, and diameter of cylinder 64 inches. In the column headed 8, and in a line with 64, there stands the number 17·59; so that according to the table the diameter would be about 17½ inches. It is obvious enough that the fly-wheel shaft stands in much the same relation to the land engine, as the paddle shaft does to the marine engine. Referring to the table in page 128; in the column headed 8, and in a line with 64, there stands the number 14·06. Hence, according to that table, the diameter of the paddle-shaft journal of a marine engine whose stroke is 8 feet, and diameter of cylinder 64 inches, is about 14 inches. The difference betwixt the diameter of the paddle shaft for the marine engine, and the diameter of the fly-wheel shaft for the corresponding land engine is about 3½ inches. This will be found to be a very proper allowance for the different circumstances connected with the land engine.

This table has been calculated from the following rule, which will be found to give correct dimensions for all sizes of engines:

Rule.—*To find the diameter of the fly-wheel shaft at smallest part, when it is of cast iron.*—*Multiply the square of the diameter of the cylinder in inches by the length of the crank in inches; extract the cube root of the product; finally multiply the result by* ·3025. *The result is the diameter of the fly-wheel shaft at smallest part in inches.*

We shall illustrate this rule by applying it to the particular engine which we have already selected.

$$\begin{array}{rl}
64 & = \text{diameter of the cylinder in inches.} \\
\underline{64} & \\
4096 & = \text{square of the diameter.} \\
\underline{48} & = \text{length of crank in inches.} \\
196608 &
\end{array}$$

$$\begin{array}{rrl}
0 & 0 & 196,608\ (58\cdot15 = \sqrt[3]{196608} \\
\underline{5} & \underline{25} & \underline{125} \\
5 & 25 & \quad 71608 \\
\underline{5} & \underline{50} & \quad \underline{70112} \\
10 & 7500 & \quad\ \ 1496 \\
\underline{5} & \underline{1264} & \quad\ \ \underline{1011} \\
150 & 8764 & \quad\ \ \ \ 485 \\
\underline{8} & \underline{1328} & \\
158 & 10092 & \\
\underline{8} & \underline{2} & \\
166 & 1011 & \\
\underline{8} & \underline{2} & \\
174 & 1013 &
\end{array}$$

and $58\cdot15 \times \cdot3025 = 17\cdot59$
which agrees with the number given in the table.

Tables in pages 148. and 149. — These tables are for determining the sectional area of the fly-wheel rim when of cast iron. The method of using them is explained in a rule in page 149. Suppose it were required to find the sectional area of the rim of a fly-wheel for an engine whose stroke is 8 feet, and diameter of cylinder 64 inches, the diameter of the fly-wheel itself being 30 feet. Referring to table A; in the column headed 8, and in a line with 64, there stands the number 146·4. Referring to table B; in the column headed 8, and in a line with 30, there stands the number ·813. Hence, according to the rule in table B, the sectional area of the rim in square inches = 146·4 × ·813 = 119·02. We may remark that these tables have been calculated on the supposition that the fly-wheel is so connected with the engine, as to make exactly one revolution for each double stroke of the piston. If the fly-wheel is so connected with the engine as to make more than one revolution for each double stroke, then the rim does not need to be so heavy as these tables would make it. If, on the contrary, the fly-wheel does not make a complete revolution for each double stroke of the engine, then it ought to be heavier than our tables make it. With regard to the rules from which these tables have been calculated, it would be useless to give a rule for each of them separately. It will be sufficient if we give a rule for determining the sectional area at once.

Rule. — *To find the sectional area of the rim of the fly-wheel, when of cast iron. —Multiply together the square of the diameter of the cylinder in inches, the square of the length of the stroke in feet, the cube root of the length of the stroke in feet, and 6·125; divide the final product by the cube of the diameter of the fly-wheel in feet. The quotient is the sectional area of the rim of fly-wheel in square inches, provided it is of cast iron.*

As this rule is rather complicated, we shall endeavour to illustrate it by showing its application to a particular engine. We shall apply the rule to determine the sectional area of the rim of fly-wheel for an engine whose stroke is 8 feet, diameter of cylinder 50 inches; the diameter of the fly-wheel being 20 feet. For this engine we have as follows:

$$\begin{array}{rl}
2500 & = \text{square of the diameter of cylinder.} \\
\underline{64} & = \text{square of the length of stroke.} \\
160000 & \\
\underline{2} & = \text{cube root of the length of stroke.} \\
320000 & \\
\underline{6\cdot125} & = \text{constant multiplier.} \\
1960000 &
\end{array}$$

therefore sectional area in square inches $= 1960000 \div 20^3 = 1960000 \div 8000 = 1960 \div 8 = 245$.

We would find the same area from the table thus. Referring to table A; and in the column headed 8 and in a line with 50, there stands the number 89·29. Referring to table B; in the column headed 8, and in a line with 20, there stands the number 2·74. Hence, according to the rule given in the heading to table B, sectional area of fly-wheel rim in square inches $= 89\cdot29 \times 2\cdot74 = 244\cdot66$; or very nearly 245 square inches.

We may here introduce the remainder of the formulæ from which the preceding tables have been calculated, which we omitted at page 106. In the following formulæ we denote the diameter of the cylinder in inches by D, the length of the crank in inches by R, the length of the stroke in feet, and the nominal horse power of the engine by H. P.

MARINE ENGINES. — DIMENSIONS OF SEVERAL OF THE PARTS OF THE SIDE LEVER.

Depth of eye round end studs of lever $= \cdot074 \times D$.
Thickness of eye round end studs of lever $= \cdot052 \times D$.
Diameter of end studs, in inches $= \cdot07 \times D$.
Length of end studs, in inches $= \cdot076 \times D$.
Diameter of air-pump studs, in inches $= \cdot045 \times D$.
Length of air-pump studs, in inches $= \cdot049 \times D$.

Depth of cast-iron side lever across centre, in inches $= D^{\frac{2}{3}} \times \{\cdot7423 \times \text{length of lever in feet}\}^{\frac{1}{3}}$.

MARINE ENGINE. — DIMENSIONS OF SEVERAL PARTS OF AIR-PUMP CROSS-HEAD.

Diameter of air-pump, in inches $= \cdot6 \times D$.
Thickness of eye for air-pump rod, in inches $= \cdot025 \times D$.
Depth of eye for air-pump rod, in inches $= \cdot171 \times D$.
Diameter of end journals, in inches $= \cdot051 \times D$.
Length of end journals, in inches $= \cdot058 \times D$.
Thickness of web at middle, in inches $= \cdot043 \times D$.
Depth of web at middle, in inches $= \cdot161 \times D$.
Thickness of web at journal $= \cdot037 \times D$.
Depth of web at journal $= \cdot061 \times D$.

MARINE ENGINE. — DIMENSIONS OF THE PARTS OF AIR-PUMP PISTON ROD.

Diameter of air-pump piston rod when of copper, in inches $= \cdot067 \times D$.
Depth of gibs and cutter through cross-head, in inches $= \cdot063 \times D$.
Thickness of gibs and cutter through cross-head, in inches $= \cdot013 \times D$.
Depth of cutter through piston, in inches $= \cdot051 \times D$.
Thickness of cutter through piston, in inches $= \cdot021 \times D$.

MARINE ENGINE. — DIMENSIONS OF THE REMAINING PARTS OF THE AIR-PUMP MACHINERY.

Diameter of air-pump side rods at ends, in inches $= \cdot039 \times D$.
Breadth of butt, in inches $= \cdot046 \times D$.
Thickness of butt, in inches $= \cdot037 \times D$.
Mean thickness of strap at cutter, in inches $= \cdot019 \times D$.
Mean thickness of strap below cutter, in inches $= \cdot014 \times D$.
Depth of gibs and cutter, in inches $= \cdot048 \times D$.
Thickness of gibs and cutter, in inches $= D \div 100$.

MARINE AND LAND ENGINES. — AREA OF STEAM PORTS.

Area of each steam port, in square inches $= 11 \times l \times D^2 \div 1800 + 8$.

MARINE AND LAND ENGINES. — DIMENSIONS OF BRANCH STEAM PIPES.

Diameter of each branch steam pipe $= \sqrt{\cdot00498 \times l \times D^2 + 10\cdot2}$.

MARINE ENGINE. — DIMENSIONS OF SEVERAL OF THE PIPES CONNECTED WITH THE ENGINE.

Diameter of waste water-pipe, in inches $= 1\cdot2 \times \sqrt{\text{H. P.}}$
Area of foot-valve passage, in square inches $= 1\cdot8 \times \text{H. P.} + 8$.
Area of injection pipe, in square inches $= \cdot069 \times \text{H. P.} + 2\cdot81$.
Diameter of feed-pipe, in inches $= \sqrt{\cdot04 \times \text{H. P.} + 3}$.
Diameter of waste steam-pipe, in inches $= \sqrt{\cdot375 \times \text{H. P.} + 16\cdot875}$.

MARINE AND LAND ENGINES. — DIMENSIONS OF SAFETY-VALVES.

Diameter of safety-valve, when one only is used $= \sqrt{\cdot5 \times \text{H. P.} + 22\cdot5}$.
Diameter of safety-valve, when two are used $= \sqrt{\cdot25 \times \text{H. P.} + 11\cdot25}$.
Diameter of safety-valve, when three are used $= \sqrt{\cdot167 \times \text{H. P} + 7\cdot5}$.
Diameter of safety-valve, when four are used $= \sqrt{\cdot125 \times \text{H. P.} + 5\cdot625}$.

LAND ENGINE. — DIMENSIONS OF MAIN BEAM.

Depth of web of main beam across centre $=$

$$\sqrt[3]{3 \times D^2 \times \text{half length of main beam in feet}}.$$

Depth of main beam at ends $=$

$$\sqrt[3]{\cdot192 \times D^2 \times \text{half length of main beam, in feet}}.$$

LAND AND MARINE ENGINES. — CONTENT OF FEED-PUMP.

Content of feed-pump, in cubic inches $= D^2 \times l \div 30$.

LAND ENGINES. — CONTENT OF COLD-WATER PUMP.

Content of cold-water pump, in cubic feet $= D^2 \times l \div 4400$.

LAND ENGINES. — DIMENSIONS OF CRANK.

Thickness of large eye of crank, in inches $=$

$$\sqrt[3]{D^2 \times (1\cdot561 \times R^2 + \cdot1235\,D^2) + (R \times 666\cdot283)}.$$

Breadth of web of crank at fly-wheel shaft centre, in inches $=$

$$\sqrt[3]{D^2 \times \sqrt{(1\cdot561 \times R^2 + \cdot1235 \times D^2)} \div 23\cdot04}.$$

Thickness of web of crank at fly-wheel shaft centre, in inches $=$

$$\sqrt[3]{D^2 \times \sqrt{(1\cdot561 \times R^2 + \cdot1235 \times D^2)} \div 184\cdot32}.$$

LAND ENGINES. — DIMENSIONS OF FLY-WHEEL SHAFT.

Diameter of fly-wheel shaft, when of cast-iron, $= 3025 \times \sqrt[3]{R \times D^2}$.

CHAPTER VII.

DIMENSIONS OF PARTS OF LOCOMOTIVES.

DIAMETER OF CYLINDER.

In locomotive engines the diameter of the cylinder varies less than in either the land or the marine engine. In few of the locomotive engines at present in use is the diameter of the cylinder greater than 16 inches, or less than 12 inches. The length of the stroke of nearly all the locomotive engines at present in use is 18 inches, and there are always two cylinders, which are generally connected to cranks upon the axle, standing at right angles with one another. Outside cylinders, operating upon pins in the driving wheels, have latterly been largely introduced; but they cause much oscillation of the engine; though this defect might be remedied by making the pistons move simultaneously, and putting another cylinder in the centre of the carriage to act upon a crank at right angles with the pins.

AREA OF INDUCTION PORTS.

Rule. — *To find the size of the steam ports for the locomotive engine.* — Multiply the square of the diameter of the cylinder by ·068. *The product is the proper size of the steam ports in square inches.*

Example. — Required the proper size of the steam ports of a locomotive engine whose diameter is 15 inches. Here, according to the rule, size of steam ports $= \cdot068 \times 15 \times 15 = \cdot068 \times 225 = 15\cdot3$ square inches, or between 15¼ and 15½ square inches.

After having determined the area of the ports, we may easily find the depth when the length is given, or, conversely, the length when the depth is given. Thus, suppose we knew the length was 8 inches, then we find that the depth should be $15\cdot3 \div 8 = 1\cdot9125$ inches, or nearly 2 inches; or suppose we knew the depth was 2 inches, then we would find that the length was $15\cdot3 \div 2 = 7\cdot65$ inches, or nearly 7¾ inches.

AREA OF EDUCTION PORTS.

The proper area for the eduction ports may be found from the following rule.

Rule. — *To find the area of the eduction ports.* — *Multiply the square of the diameter of the cylinder in inches by* ·128. *The product is the area of the eduction ports in square inches.*

Example. — Required the area of the eduction ports of a locomotive engine, when the diameter of the cylinders is 13 inches. In this example we have, according to the rule,

area of eduction port $= \cdot128 \times 13^2 = \cdot128 \times 169 = 21\cdot632$ inches,

or between 21½ and 21¾ square inches.

BREADTH OF BRIDGE BETWEEN PORTS.

The breadth of the bridges between the eduction port and the induction ports is usually between ¾ inch and 1 inch.

DIAMETER OF BOILER.

It is obvious that the diameter of the boiler may vary very considerably; but it is limited chiefly by considerations of strength; and 3 feet is found a convenient diameter. Some rules for the strength of boilers are given at page 230.

Rule. — *To find the inside diameter of the boiler.* — *Multiply the diameter of the cylinder in inches by* 3·11. *The product is the inside diameter of the boiler in inches.*

Example. — Required the inside diameter of the boiler for a locomotive engine, the diameter of the cylinders being 15 inches.

In this example we have, according to the rule,

inside diameter of boiler $= 15 \times 3\cdot11 = 46\cdot65$ inches,

or about 3 feet 10⅝ inches.

LENGTH OF BOILER.

The length of the boiler is usually in practice between 8 feet and 8½ feet. In the Northern and Eastern Counties Railway the length of the boiler is 8 feet; while in the North Midland Counties Railway, in the Great Western Railway, and in the Hartlepool Railway, the length of the boiler is 8½ feet. In the Belgian railways the length of the boiler is 8 feet 2 inches. And in the Bourdeaux et La Teste railway the length of the boiler is 8 feet 9 inches. In Stephenson's specification for improvements in the arrangement and combination of the parts of locomotive engines, the length of the boiler is between 11 and 12 feet.

DIAMETER OF STEAM DOME INSIDE.

It is obvious that the diameter of the steam dome may be varied considerably, according to circumstances; but the first indication is to make it large enough. It is usual, however, in practice, to proportion the diameter of the steam dome to the diameter of the cylinder; and there appears to be no great objection to this. The following rule will be found to give the diameter of the dome usually adopted in practice.

Rule. — *To find the diameter of the steam dome.* — *Multiply the diameter of the cylinder in inches by* 1·43. *The product is the diameter of the dome in inches.*

Example. — Required the diameter of the steam dome for a locomotive engine whose diameter of cylinders is 13 inches. In this example we have, according to the rule,

diameter of steam dome $= 1\cdot43 \times 13 = 18\cdot59$ inches, or about 18½ inches.

HEIGHT OF STEAM DOME.

The height of the steam dome may vary. Judging from practice, it appears that a uniform height of 2½ feet would answer very well.

DIAMETER OF SAFETY VALVE.

In practice the diameter of the safety valve varies considerably. The following rule gives the diameter of the safety valve usually adopted in practice.

Rule. — *To find the diameter of the safety valve.* — *Divide the diameter of the cylinder in inches by* 4. *The quotient is the diameter of the safety valve in inches.*

Example. — Required the diameter of the safety valves for the boiler of a locomotive engine, the diameter of the cylinder being 13 inches. Here, according to the rule, diameter of safety valve $= 13 \div 4 = 3\frac{1}{4}$ inches. A larger size, however, is preferable, as being less likely to stick.

DIAMETER OF VALVE SPINDLE.

The following rule will be found to give the correct diameter of the valve spindle. It is entirely founded on practice.

Rule. — *To find the diameter of the valve spindle.* — *Multiply the diameter of the cylinder in inches by* ·076. *The product is the proper diameter of the valve spindle.*

Example. — Required the diameter of the valve spindle for a locomotive engine whose cylinders' diameters are 13 inches.

In this example we have, according to the rule,

diameter of valve spindle $= 13 \times \cdot076 = \cdot988$ inches, or very nearly 1 inch.

DIAMETER OF CHIMNEY.

It is usual in practice to make the diameter of the chimney equal to the diameter of the cylinder. Thus a locomotive engine whose cylinders' diameters are 15 inches would have the inside diameter of the chimney also 15 inches, or thereabouts. This rule has, at least, the merit of simplicity.

AREA OF FIRE-GRATE.

The following rule determines the area of the fire-grate usually given in practice. We may remark, that the area of the fire-grate in practice follows a more certain rule than any other part of the engine appears to do; but it is in all cases much too small, and occasions a great loss of power by the urging of the blast it renders necessary, and a rapid deterioration of the furnace plates from excessive heat. There is no good reason why the furnace should not be nearly as long as the boiler: it would then resemble the furnace of a marine boiler, and be as manageable.

Rule.—*To find the area of the fire-grate.—Multiply the diameter of the cylinder in inches by ·77. The product is the area of the fire-grate in superficial feet.*

Example.—Required the area of the fire-grate of a locomotive engine, the diameters of the cylinders being 15 inches.

In this example we have, according to the rule,

area of fire-grate $= {\cdot}77 \times 15 = 11{\cdot}55$ square feet,

or about 11½ square feet. Though this rule, however, represents the usual practice, the area of fire-grate should not be contingent upon the size of the cylinder, but upon the quantity of steam to be raised.

AREA OF HEATING SURFACE.

In the construction of a locomotive engine, one great object is to obtain a boiler which will produce a sufficient quantity of steam with as little bulk and weight as possible. This object is admirably accomplished in the construction of the boiler of the locomotive engine. This little barrel of tubes generates more steam in an hour than was formerly raised from a boiler and fire occupying a considerable house. This favourable result is obtained simply by exposing the water to a greater amount of heating surface.

In the usual construction of the locomotive boiler, it is obvious that we can only consider four of the six faces of the inside fire-box as effective heating surface; viz. the crown of the box, and the three perpendicular sides. The circumferences of the tubes are also effective heating surface; so that the whole effective heating surface of a locomotive boiler may be considered to be the four faces of the inside fire-box, plus the sum of the surfaces of the tubes. Understanding this to be the effective heating surface, the following rule determines the average amount of heating surface usually given in practice.

Rule.—*To find the effective heating surface.—Multiply the square of the diameter of the cylinder in inches by 5; divide the product by 2. The quotient is the area of the effective heating surface in square feet.*

Example.—Required the effective heating surface of the boiler of a locomotive engine, the diameters of the cylinders being 15 inches.

In this example we have, according to the rule,

effective heating surface $= 15^2 \times 5 \div 2 = 225 \times 5 \div 2 = 1125 \div 2 = 562\frac{1}{2}$ square feet.

According to the rule which we have given for the fire-grate, the area of the fire-grate for this boiler would be about 11½ square feet. We may suppose, therefore, the area of the crown of the box to be 12 square feet. The area of the three perpendicular sides of the inside fire-box is usually three times the area of the crown; so that the effective heating surface of the fire box is 48 square feet. Hence the heating surface of the tubes $= 526{\cdot}5 - 48 = 478{\cdot}5$ square feet. The inside diameters of the tubes are generally about 1¾ inches; and therefore the circumference of a section of these tubes, according to the table in page 24, is 5·4978 inches. Hence, supposing the tube to be 8½ feet long, the surface of one $= 5{\cdot}4978 \times 8\frac{1}{2} \div 12 = {\cdot}45815 \times 8\frac{1}{2} = 3{\cdot}8943$ square feet. And, therefore, the number of tubes $= 478{\cdot}5 \div 3{\cdot}8943 = 123$ nearly. The amount of heating surface, however, like that of grate surface, is properly a function of the quantity of steam to be raised, and the proportions of both, given at page 229, will be found to answer well for boilers of every description.

AREA OF WATER-LEVEL.

This of course varies with the different circumstances of the boiler. The average area may be found from the following rule.

Rule.—*To find the area of the water-level.—Multiply the diameter of the cylinder in inches by* 2·08. *The product is the area of the water-level in square feet.*

Example.—Required the area of the water-level for a locomotive engine, whose cylinders' diameters are 14 inches.

In this case we have, according to the rule,

area of water-level $= 14 \times 2{\cdot}08 = 29{\cdot}12$ square feet.

CUBICAL CONTENT OF WATER IN BOILER.

This of course varies not only in different boilers, but also in the same boiler at different times. The following rule is supposed to give the average quantity of water in the boiler.

Rule.—*To find the cubical content of the water in the boiler.—Multiply the square of the diameter of the cylinder in inches by 9; divide the product by* 40. *The quotient is the cubical content of the water in the boiler in cubic feet.*

Example.—Required the average cubical content of the water in the boiler of a locomotive engine, the diameters of the cylinders being 14 inches. In this example we have, according to the rule,

cubical content of water $= 9 \times 14^2 \div 40 = 44{\cdot}1$ cubic feet.

CONTENT OF FEED-PUMP.

In the locomotive engine, the feed-pump is generally attached to the cross-head, and consequently it has the same stroke as the piston. As we have mentioned before, the stroke of the locomotive engine is generally in practice 18 inches. Hence, assuming the stroke of the feed-pump to be constantly 18 inches, it only remains for us to determine the diameter of the ram. It may be found from the following rule.

Rule.—*To find the diameter of the feed-pump ram.—Multiply the square of the diameter of the cylinder in inches by* ·011. *The product is the diameter of the ram in inches.*

Example.—Required the diameter of the ram for the feed-pump for a locomotive engine whose diameter of cylinder is 14 inches. In this example we have, according to the rule,

diameter of ram $= {\cdot}011 \times 14^2 = {\cdot}011 \times 196 = 2{\cdot}156$ inches,

or between 2 and 2¼ inches.

CUBICAL CONTENT OF STEAM ROOM.

The quantity of steam in the boiler varies not only for different boilers, but even for the same boiler in different circumstances. But when the locomotive is in motion, there is usually a certain proportion of the boiler filled with the steam. Including the dome and the steam pipe, the content of the steam room will be found usually to be somewhat less than the cubical content of the water. But as it is desirable that it should be increased, we give the following rule.

Rule.—*To find the cubical content of the steam room.—Multiply the square of the diameter of the cylinder in inches by 9; divide the product by* 40. *The quotient is the cubical content of the steam room in cubic feet.*

Example.—Required the cubical content of the steam room in a locomotive boiler, the diameters of the cylinders being 12 inches.

In this example we have, according to the rule,

cubical content of steam room $= 9 \times 12^2 \div 40 = 9 \times 144 \div 40 = 32{\cdot}4$ cubic feet.

CUBICAL CONTENT OF INSIDE FIRE-BOX ABOVE FIRE-BARS.

The following rule determines the cubical content of fire-box usually given in practice.

Rule.—*To find the cubical content of inside fire-box above fire-bars.—Divide the square of the diameter of the cylinder in inches by 4. The quotient is the content of the inside fire-box above fire-bars in cubic feet.*

Example.—Required the content of inside fire-box above fire-bars in a locomotive engine, when the diameters of the cylinders are each 15 inches.

In this example we have, according to the rule,

content of inside fire-box above fire-bars $= 15^2 \div 4 = 225 \div 4 = 56\frac{1}{4}$ cubic ft.

THICKNESS OF THE PLATES OF BOILER.

In general the thickness of the plates of the locomotive boiler is ⅜ inch. In some cases, however, the thickness is only $\frac{5}{16}$ inch.

INSIDE DIAMETER OF STEAM PIPE.

The diameter usually given to the steam pipe of the locomotive engine may be found from the following rule.

Rule.—*To find the diameter of the steam pipe of the locomotive engine.—Multiply the square of the diameter of the cylinder in inches by* ·03. *The product is the diameter of the steam pipe in inches.*

Example.—Required the diameter of the steam pipe of a locomotive engine, the diameter of the cylinder being 13 inches. Here, according to the rule, diameter of steam pipe $= {\cdot}03 \times 13^2 = {\cdot}03 \times 169 = 5{\cdot}07$ inches; or a very little more than 5 inches. The steam pipe is usually made too small in engines intended for high speeds.

DIAMETER OF BRANCH STEAM PIPES.

The following rule gives the usual diameter of the branch steam pipe for locomotive engines.

Rule.—*To find the diameter of the branch steam pipe for the locomotive engine.—Multiply the square of the diameter of the cylinder in inches by* ·021. *The product is the diameter of the branch steam pipe for the locomotive engine in inches.*

Example.—Required the diameter of the branch steam pipes for a locomotive engine, when the cylinder's diameter is 15 inches. Here, according to the rule, diameter of branch pipe $= {\cdot}021 \times 15^2 = {\cdot}021 \times 225 = 4{\cdot}725$ inches, or about 4¾ inches.

DIAMETER OF TOP OF BLAST PIPE.

The diameter of the top of the blast pipe may be found from the following rule.

Rule.—*To find the diameter of the top of the blast pipe.—Multiply the square of the diameter of the cylinder in inches by* ·017. *The product is the diameter of the top of the blast pipe in inches.*

Example.—The diameter of a locomotive engine is 13 inches; required the diameter of the blast pipe at top. Here, according to the rule,

diameter of blast pipe at top $= {\cdot}017 \times 13^2 = {\cdot}017 \times 169 = 2{\cdot}873$ inches, or between 2¾ and 3 inches; but the orifice of the blast pipe should always be made as large as the demands of the blast will permit.

DIAMETER OF FEED PIPES.

There appear to be no theoretical considerations which would lead us to determine exactly the proper size of the feed pipes. Judging from practice, however, the following rule will be found to give the proper dimensions.

Rule. — *To find the diameter of the feed pipes.—Multiply the diameter of the cylinder in inches by* ·141. *The product is the proper diameter of the feed pipes.*

Example.— Required the diameter of the feed pipes for a locomotive engine, the diameter of the cylinder being 15 inches.

In this example we have, according to the rule,

diameter of feed-pipe = 15 × ·141 = 2·115 inches,

or between 2 and 2⅛ inches.

DIAMETER OF PISTON ROD.

The diameter of the piston rod for the locomotive engine is usually about one-seventh the diameter of the cylinder. Making practice our guide, therefore, we have the following rule.

Rule. — *To find the diameter of the piston rod for the locomotive engine.— Divide the diameter of the cylinder in inches by* 7. *The quotient is the diameter of the piston rod in inches.*

Example. — The diameter of the cylinder of a locomotive engine is 15 inches, required the diameter of the piston rod. Here, according to the rule, diameter of piston rod = 15 ÷ 7 = 2⅐ inches.

THICKNESS OF PISTON.

The thickness of the piston in locomotive engines is usually about two-sevenths of the diameter of the cylinder. Making practice our guide, therefore, we have the following rule.

Rule. — *To find the thickness of the piston in the locomotive engine.— Multiply the diameter of the cylinder in inches by* 2; *divide the product by* 7. *The quotient is the thickness of the piston in inches.*

Example. — The diameter of the cylinder of a locomotive engine is 14 inches, required the thickness of the piston. Here, according to the rule, thickness of piston = 2 × 14 ÷ 7 = 4 inches.

DIAMETER OF CONNECTING RODS AT MIDDLE.

The following rule gives the diameter of the connecting rod at middle. The rule, we may remark, is entirely founded on practice.

Rule. — *To find the diameter of the connecting rod at middle of the locomotive engine.—Multiply the diameter of the cylinder in inches by* ·21. *The product is the diameter of the connecting rod at middle in inches.*

Example. — Required the diameter of the connecting rods at middle for a locomotive engine, the diameter of the cylinders being twelve inches.

For this example we have, according to the rule,

diameter of connecting rods at middle = 12 × ·21 = 2·52 inches, or 2½ inches.

DIAMETER OF BALL ON CROSS-HEAD SPINDLE.

The diameter of the ball on the cross-head spindle may be found from the following rule.

Rule. — *To find the diameter of the ball on cross-head spindle of a locomotive engine.—Multiply the diameter of the cylinder in inches by* ·23. *The product is the diameter of the ball on the cross-head spindle.*

Example. —Required the diameter of the ball on the cross-head spindle of a locomotive engine, when the diameter of the cylinder is 15 inches. Here, according to the rule,

diameter of ball = ·23 × 15 = 3·45 inches, or nearly 3½ inches.

DIAMETER OF THE INSIDE BEARINGS OF THE CRANK AXLE.

It is obvious that the inside bearings of the crank axle of the locomotive engine correspond to the paddle-shaft journal of the marine engine, and to the fly-wheel shaft journal of the land engine. We may conclude, therefore, that the proper diameter of these bearings ought to depend jointly upon the length of the stroke and the diameter of the cylinder. In the locomotive engine the stroke is usually 18 inches, so that we may consider that the diameter of the bearing depends solely upon the diameter of the cylinder. The following rule will give the diameter of the inside bearing.

Rule. — *To find the diameter of the inside bearing for the locomotive engine. Extract the cube root of the square of the diameter of the cylinder in inches; multiply the result by* ·96. *The product is the proper diameter of the inside bearing of the crank axle for the locomotive engine.*

Example. — Required the diameter of the inside bearing of the crank axle for a locomotive engine whose cylinders are of 13-inch diameters. In this example we have, according to the rule,

```
 13 = diameter of cylinder in inches.
 13
----
169 = square of the diameter of cylinder.

  0        0        169(5·5289 = ∛169
  5       25        125
 --       --        -----
  5       25         44000
  5       50         41375
 --      ----        -----
 10     7500          2625
  5      775          1820
---     ----          ----
150     8275           805
  5      800           726
---     ----           ---
155     9075            79
  5        3
---     ----
160      910
  5        3
---     ----
165      913
```

and diameter of bearing = 5·5289 × ·96 = 5·31 inches nearly; or between 5¼ and 5½ inches.

DIAMETER OF PLAIN PART OF CRANK AXLE.

It is usual to make the plain part of crank axle of the same sectional area as the inside bearings. Hence, to determine the sectional area of the plain part when it is cylindrical, we have the following rule.

Rule. — *To determine the diameter of the plain part of crank axle for the locomotive engine.—Extract the cube root of the square of the diameter of the cylinder in inches; multiply the result by* ·96. *The product is the proper diameter of the plain part of the crank axle of the locomotive engine in inches.*

Example.—Required the diameter of the plain part of the crank axle for the locomotive engine, whose cylinders' diameters are 14 inches. In this example we have, according to the rule,

```
            14 = diameter of cylinder in inches.
            14
           ----
           196 = square of the diameter of cylinder.

  0        ·0        196(5·808 = ∛196
  5        25        125
 --        --        ------
  5        25         71·000
  5        50         70·112
 --      ----         ------
 10      7500           ·888
  5      1264
---      ----
150      8764
  8      1328
---     -----
158     10092
  8
---
166
  8
---
174
```

and diameter of plain part of crank axle = 5·808 × ·96 = 5·58 inches nearly, or a little more than 5½ inches.

DIAMETER OF THE OUTSIDE BEARINGS OF THE CRANK AXLE.

The crank axle, in addition to resting upon the inside bearings, is sometimes also made to rest partly upon outside bearings. These outside bearings are added only for the sake of steadiness, and they do not need to be so strong as the inside bearings. The proper size of the diameter of these bearings may be found from the following rule.

Rule. — *To find the diameter of outside bearings for the locomotive engine.— Multiply the square of the diameter of the cylinders in inches by* ·396; *extract the cube root of the product. The result is the diameter of the outside bearings in inches.*

Example. — Required the proper diameter of the outside bearings for a locomotive engine, the diameter of its cylinders being 15 inches.

In this example we have, according to the rule,

```
  15 = diameter of cylinders in inches.
  15
 ----
 225 = square of diameter of cylinder.
·396 = constant multiplier.
-----
89·1
```

```
  0        0          89·1(4·466 = ∛89·1
  4       16          64
 --      ---          -----
  4       16          25100
  4       32          21184
 --      ----         -----
  8     4800           3916
  4      496           3528
---     ----           ----
120     5296            388
  4      512            358
---     ----            ---
124     5808
  4        8
---     ----
128      588
  4        8
---     ----
132      596
```

Hence diameter of outside bearing = 4·466 inches, or very nearly 4½ inches.

DIAMETER OF CRANK PIN.

The following rule gives the proper diameter of the crank pin. It is obvious that the crank pin of the locomotive engine is not altogether analogous to the crank pin of the marine or land engine, and, like them, ought to depend upon the diameter of the cylinder, as it is usually formed out of the solid axle.

Rule. — *To find the diameter of the crank pin for the locomotive engine. — Multiply the diameter of the cylinder in inches by ·404. The product is the diameter of the crank pin in inches.*

Example. — Required the diameter of the crank pin of a locomotive engine whose cylinders' diameters are 15 inches.

In this example we have, according to the rule,

diameter of crank pin = 15 × ·404 = 6·06 inches, or about 6 inches.

LENGTH OF CRANK PIN.

The length of the crank pin usually given in practice may be found from the following rule.

Rule. — *To find the length of the crank pin. — Multiply the diameter of the cylinder in inches by ·233. The product is the length of the crank pins in inches.*

Example. — Required the length of the crank pins for a locomotive engine with a diameter of cylinder of 13 inches.

In this example we have, according to the rule,

length of crank pin = 13 × ·233 = 3·029 inches,

or about 3 inches. The part of the crank axle answering to the crank pin is usually rounded very much at the corners, both to give additional strength, and to prevent side play.

These then are the chief dimensions of locomotive engines, according to the practice most generally followed. The establishment of express trains and the general exigencies of steam locomotion are daily introducing innovations, the effect of which is to make the engines of greater size and power: but it cannot be said that a plan of locomotive engine has yet been contrived that is free from grave objections. The most material of these defects is the necessity that yet exists of expending a large proportion of the power in the production of a draft; and this evil is traceable to the inadequate area of the fire-grate, which makes an enormous rush of air through the fire necessary to accomplish the combustion of the fuel requisite for the production of the steam. To gain a sufficient area of fire-grate an entirely new arrangement of engine must be adopted: the furnace must be greatly lengthened, and perhaps it may be found that short upright tubes of the kind employed in the boiler at page 68 may be introduced with advantage. Upright tubes have been found to be more effectual in raising steam than horizontal tubes; but the tube plate in the case of upright tubes would be more liable to burn.

We here give the preceding rules in formulæ, in the belief that those well-acquainted with algebraic symbols prefer to have a rule expressed as a formula, as they can thus see at once the different operations to be performed. In the following formulas we denote the diameter of the cylinder in inches by D.

LOCOMOTIVE ENGINE. — PARTS OF THE CYLINDER.

Area of induction ports, in square inches = ·068 × D^2.
Area of eduction ports, in square inches = ·128 × D^2.
Breadth of bridge between ports between ¾ inch and 1 inch.

LOCOMOTIVE ENGINE. — PARTS OF BOILER.

Diameter of boiler, in inches = 3·11 × D.
Length of boiler between 8 feet and 12 feet.
Diameter of steam dome inside, in inches = 1·43 × D.
Height of steam dome = 2½ feet.
Diameter of safety valve, in inches = D + 4.
Diameter of valve spindle, in inches = ·076 × D.
Diameter of chimney, in inches = D.
Area of fire-grate, in square feet = ·77 × D.
Area of heating surface, in square feet = 5 × $D^2 \div 2$.
Area of water-level, in square feet = 2·08 × D.
Cubical content of water in boiler, in cubic feet = 9 × $D^2 \div 40$.
Diameter of feed-pump ram, in inches = ·011 × D^2.
Cubical content of steam room, in cubic feet = 9 × $D^2 \div 40$.
Cubical content of inside fire-box above fire bars, in cubic feet = $D^2 \div 4$
Thickness of the plates of boiler = ⅜ inch.

LOCOMOTIVE ENGINE. — DIMENSIONS OF SEVERAL PIPES.

Inside diameter of steam pipe, in inches = ·03 × D^2.
Inside diameter of branch steam pipe, in inches = ·021 × D^2.
Inside diameter of the top of blast pipe = ·017 × D^2.
Inside diameter of the feed pipes = ·141 × D.

LOCOMOTIVE ENGINE. — DIMENSIONS OF SEVERAL MOVING PARTS.

Diameter of piston rod, in inches = D ÷ 7.
Thickness of piston, in inches = 2 D ÷ 7.
Diameter of connecting rods at middle, in inches = ·21 × D.
Diameter of the ball on cross-head spindle, in inches = ·23 × D.
Diameter of the inside bearings of the crank axle, in inches = ·96 × $\sqrt[3]{D^2}$.
Diameter of the plain part of crank axle, in inches = ·96 × $\sqrt[3]{D^2}$.
Diameter of the outside bearings of the crank axle, in inches = $\sqrt[3]{{\cdot}396 \times D^2}$
Diameter of crank pin, in inches = ·404 × D.
Length of crank pin, in inches = ·233 × D.

CHAPTER VIII.

EXPEDIENTS FOR REGULATING THE VELOCITY, AND ASCERTAINING THE STATE AND EFFECTIVE POWER OF THE ENGINE.

In most engines yet invented for developing mechanical effect from steam, there are great irregularities in the velocity of the engine unless some contrivance be added to equalise the action of the steam. In the land-engine, and in the marine-engine, the inequalities of velocity may be considered to proceed from two sources; one, the unequal action of the mechanism of the engine itself, and the other the unequal resistances which the engine has to overcome. The piston does not move with a uniform velocity up and down the cylinder. The velocity is greatest at half stroke, and gradually decreases towards the end of the stroke till it stops altogether, and finally returns in the opposite direction. When it is said that the velocity of the piston is so many feet per minute, it is at once inferred that this can only be the mean velocity, and that at the middle of the stroke the piston moves faster, and at the termination slower, than the specified velocity. But even if the piston were to move uniformly, the intervention of the crank would introduce irregularities into the velocity of the engine. The crank is certainly the best constructive expedient yet devised for deriving a rotatory motion from the reciprocating motion of the piston; but, with all its advantages, it has the defect of not transmitting uniformly the pressure and velocity of the engine. Let it not be inferred from this statement that we intend to show the least favour to the exploded notion of the crank absorbing some of the power or mechanical effect of the steam. In a former part of this work we have shown at great length that the crank, like every other piece of machinery, transmits at every instant all the mechanical effect communicated to it; so that the only way in which we can suppose it to have an appetite for devouring power is by taking into consideration the friction of the parts connected with it. But this is not inconsistent with our statement that the crank does not transmit the pressure and velocity of the piston uniformly. The mechanical effect transmitted by the crank at any instant is measured by the product of the effective pressure on the crank into its velocity at that instant; and this is exactly equal to the mechanical effect generated at the piston at the same instant, as measured by the product of the pressure on the piston into its velocity. But then the velocity of the crank does not always bear the same proportion to the velocity of the piston, nor does the effective pressure on the crank always bear the same proportion to the pressure on the piston. The products are constantly equal, but the proportions of the elements constantly change; and the effect of the intervention of the crank, if unredressed, would be to cause the velocity of the machinery driven by the engine to undergo inconvenient fluctuations.

These irregularities proceeding from the internal mechanism of the engine itself would leave the mean velocity unaffected. Supposing the amount of steam supplied, and the amount of resistance to be overcome, to remain constant, then, although the velocity would be different for different positions of the crank, still the average velocity throughout a whole revolution would remain constant. If, however, the amount of resistance to be overcome be changed, the average velocity will also change, unless the supply of steam be modified so as to suit the exigency. We may see the great variation of resistance which a marine engine has to sustain in a storm. Sometimes the paddle board is deeply immersed in the wave — at other times it is almost completely out of the water; and in these circumstances it is obvious that the average velocity of the paddle shaft will vary. Analogous variations are experienced in most of the applications of the land-engine. If a land-engine be employed to drive the machinery of a cotton mill, it will have to impart motion to all the spinning frames in that mill. The operation of one or more of these may from time to time be suspended, and consequently the moving power will be relieved from a corresponding amount of resistance, and again the spinning frames offer different resistances at different times. These circumstances, it is obvious, must affect the mean velocity of the engine, unless some contrivance be added to modify the supply of steam so as to correspond to the amount of resistance to be overcome. If, under such circumstances, the energy of the moving power remains the same, the velocity with which the machinery will be driven must be subject to variation, being increased whenever the operation of any portion of the machines usually driven by it is suspended; and, on the other hand, diminished when any increased number of machines are brought into operation In fine, the speed will vary nearly in the inverse proportion of the load driven, increasing as the load is diminished, and *vice versâ.*

Now in most of the applications of the steam engine, irregularity of velocity is considered to be a great evil, and every exertion is made to lessen it as much as possible. Indeed in all applications of machinery it is desirable, all other things being equal, to have the motion uniform. On this Tredgold remarks, very justly, "An equable motion is desirable in almost every kind of machine, it being strained much more by an irregular desultory one, as well as the fabric that supports it, than when the motion is equable. The strength of the machine must be adapted to the greatest strains that occur; but the quantity of work done is equivalent to the mean action only, and more is not performed by a desultory motion than by one at a mean rate, and uniform." But uniformity of velocity is more sought after in some of the applications of the steam engine than in others. In the marine-engine and the locomotive engine all the requisite uniformity is obtained by attaching two engines to the main shaft, and so adjusting them that the irregularities of the one engine partly counteract the irregularities of the other. The plan does not insure perfect uniformity, but it approaches to it as far as particular circumstances seem to require. In these engines no provision is made that the supply of steam should adapt itself to the amount of resistance to be overcome. Again, in the common pumping engine, there is not so much urgent necessity for uniformity of motion as in most other applications of the land-engine. Indeed, judging from practice, we may infer that the advantage to be gained by a greater uniformity in the velocity of the pumping engine is not sufficiently great to compensate for the increased expense incurred in providing and repairing a mechanism for redressing its inequalities. However, in many of the other applications of the land-engine, uniformity of velocity is the great object aimed at, and provision is made for approximating to it as closely as possible.

We have pointed out two sources of irregularity of velocity; one the peculiar internal mechanism of the engine itself, and the other the unequal resistances which it has to overcome. We proceed now to mention in detail the several remedies that have been proposed for redressing these inequalities: and first we proceed to mention those remedies which have been proposed for redressing the inequalities arising from the peculiar mechanism of the engine itself.

REMEDIES FOR REDRESSING THE INEQUALITIES ARISING FROM THE MECHANISM OF THE ENGINE ITSELF.

Before the improvements which Watt effected on the steam engine, it had never been employed for any other purpose save that of raising water by working pumps. All that was requisite for this, was an upward force capable of elevating the piston of the pump when loaded with a column of water. The piston of the cylinder, after it had made its downward stroke, was raised to the top of the cylinder by the preponderating weight of the pump piston and balance weight, and sometimes the pump end of the beam was made longer than the cylinder end. But in any case the only means employed for redressing the intermittent action of the moving agent was the preponderating weight of the pump end of the beam. These means are obviously very imperfect, and would be quite insufficient for obtaining that regularity of velocity which many of the modern applications of the steam engine to the different arts and manufactures require. But great uniformity of velocity is not an all-important desideratum in the pumping engine.

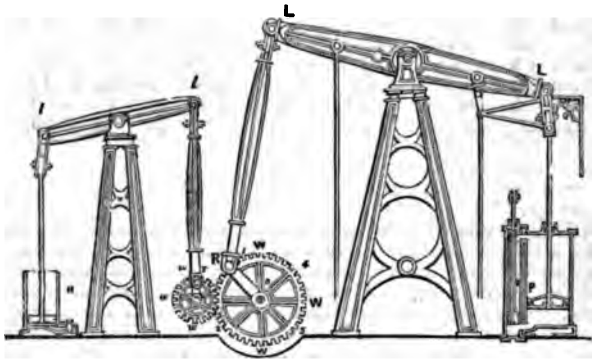
Watt's first improvements were all conducted with reference to the then prevalent application of the steam engine to pump water. His single-acting engine, like all the engines previously constructed, could only generate power in the downward stroke of the piston; and its only advantage over its predecessors was, that it extracted more useful effect from a determinate quantity of steam. The upward stroke of the piston was still effected by the preponderating weight of the pump end of the beam, but before the steam engine could be applied to other purposes than pumping water, Watt perceived that it would be necessary to drive the main beam both in the upward and downward stroke of the piston. As mentioned at page 16, he at first proposed to place a cylinder under each end of the great beam, so that when one of the pistons would be rising the other would be falling, and as the cylinders were to be supplied from the same boiler, and the steam to be condensed in the same condenser, he thought it probable that the two actions on the beam would produce a regular and uniform motion. This project was never carried into execution; it was entirely supplanted by the double-acting engine, which Watt soon afterwards constructed. But even although it had been carried into execution, it would obviously have come very far short of producing a perfectly uniform velocity.

We have already mentioned, that in the marine engine and locomotive engine an approximation to uniformity of velocity and uniformity of pressure is obtained by putting two engines upon the same shaft, and so adjusting them that when the piston of the one engine is at its maximum velocity, the piston of the other is at its minimum, and *vice versâ*. This is effected by placing the cranks at right angles to one another. The velocity obtained in this way is more nearly uniform than when only one engine is used, but, unless assisted by a fly-wheel, the irregularities would be too great for many of the nice applications of the modern steam engine. Another objection to this plan is, that it requires two engines, and thus takes up more room, and offers more constructive difficulties, than if the requisite power were obtained from one engine only. These objections are to a certain extent obviated by an ingenious plan first proposed by Mr. Mark Isambard Brunel, and for which he obtained a patent in 1823. In his plan, instead of using two cranks, two cylinders are employed to give motion to the same crank. This is effected by inclining the two cylinders to one another at an angle of about 90°, and causing them to act upon the same axle by means of their connecting rods. The frame of the engine is of the form of an isosceles triangle. The working cylinders rest upon the inclined sides, and the main shaft, upon the apex of the triangle. The piston-rod is preserved in its rectilineal course by metal rollers running upon guide plates, which act a similar part to the vertical guides in the common direct-action engine. Mr. Brunel states that the axis of the cylinders should be inclined to one another at an angle of 102°; having, as he says, found that angle to be preferable to all others for transmitting a rotatory motion to the axle from the reciprocating motion of the pistons: but there seems to be no theoretical considerations which would lead us to prefer an angle of 102° to an angle of 90°, except that the weight of the pistons and their connections presses only in a downward direction. Underneath each of the working cylinders is placed a small cylinder containing the valve. The valves are wrought by eccentrics from the main shaft, and the steam is alternately admitted into one end of the working cylinder, and a passage opened for its escape at the other, as is the usual arrangement. From this form of construction it follows, that when the piston of one of the cylinders is at half-stroke, the piston of the other is at the termination of its stroke, or nearly so; and thus the irregularities of the one cylinder partly counteract the irregularities of the other. It is obvious, however, that this engine, whatever may be its peculiar advantages in other respects, will fail in obtaining any greater regularity of velocity than is obtained in the more usual construction, by placing two marine engines or two locomotive engines upon the same shaft—a motion which of itself is too irregular for many of the modern applications of the steam engine.

When the expansive principle is employed in an engine, it involves the condition of a variation in the intensity of the moving power. If the steam acts with a uniform energy on the piston as long as the supply from the boiler continues, so soon as that supply is stopped by closing the steam valve, the steam contained in the cylinder will fill a gradually increasing volume by the motion of the piston, and consequently will act above the piston with a gradually decreasing energy. Now, if the resistance to the moving power be not subject to a variation corresponding exactly to this variation in the moving power, the result will be that the motion will cease to be uniform. For if the momentum of the moving power at any part of the stroke be greater than the resistance, the motion of the machinery will be accelerated; and if it be less, the motion of the machinery will be retarded. Hence the application of the expansive principle will introduce irregularities peculiar to itself. In the patent which Watt took out for the application of the expansive principle, he specified several expedients for approximating to a uniform effect upon a uniform resistance, notwithstanding the variation of the energy of the power which necessarily attended the expansion of the steam. One method consisted in causing the moving force, when acting with the greatest energy, to impart momentum to a mass of inert matter, which should be made to restore the same force when the moving power was more enfeebled. Another expedient consisted in causing the moving power, when acting with greatest energy, to lift a weight hung considerably above the centre of the beam which should resist the ascent of the piston at the beginning of the stroke, but aid its motion as soon as the beam passed the horizontal line, when the weight, like a tumbler, would pass its centre of gravity. He also proposed to make the piston act on a lever, which should have an arm of variable length, and so regulated, that when the momentum of the moving force increased or diminished, the length of the arm diminished or increased in the same proportion. This last expedient had been already applied in mechanics for the purpose of equalising a varying power, and a familiar example of its action occurs in the internal mechanism of a watch. When a watch is newly wound up, the force of the spring is much greater than when the watch is nearly run down; so that if the force of the spring always acted at the same leverage, a very unequal velocity would be produced. The irregularity, however, is counteracted by the varying diameters of the grooves of the fusee, on which the force of the spring, through the intervention of the chain, acts. As the watch goes down, the main-spring relaxes, and its force diminishes; but then the chain acts upon a wheel or circle having a diameter increased in the same proportion as the strength of the spring is diminished. This expedient, however, has never been successfully employed to regulate the action of the moving power of the steam engine; and it does not appear to be as practicable a scheme as that of hanging a weight above the centre of the beam.

The following ingenious expedient for equalising the action of the steam in the engine, was first suggested by Mr. Buckle of Soho, and constructed by him for Mr. Lucy of Birmingham. It acts upon the principle of causing the engine to drag up a piston against the pressure of the atmosphere when the energy of the moving power is above the average; the power thus consumed being returned to the engine by the atmosphere forcing down the piston when the energy of the moving power is below the average. The manner in which this is accomplished may be easily understood from the accompanying figure. P represents the piston in the cylinder, L L the great beam, L R the connecting rod, R O the crank, and R W W W a toothed wheel carrried round by the crank. These are all the same as in the common steam engine. There is added *r w w w*, a smaller wheel, whose diameter is only one half that of the larger, and consequently it has only one half the number of teeth. The small wheel will obviously perform a half revolution whilst the large wheel performs a quarter revolution. *l l* is a second lever, driven by the crank of the small wheel, to which it is attached by means of its connecting-rod. The piston-rod *l* H is attached to the small lever *l l*, carrying with it a piston from top to bottom of an open cylinder H. At the points marked 1, 2, 3, 4, the circumference of the great wheel is supposed to be divided into four equal quadrants. Suppose now that the figure represents the state of the engine when the piston is ascending. Whilst the crank moves from its present position to the position corresponding to 2, the small wheel will have performed a semi-revolution, and the piston H will have ascended to the top of the open cylinder, leaving a vacuum behind it. The piston H has been dragged up against the pressure of the atmosphere, and this has consumed so much of the power of the engine. This power, however, is not lost—it is only lent: for while the crank moves from the position 2 to the position 3, the pressure of the air forces down the piston, and then the mechanical power is given back to the large wheel. Again, whilst the crank moves from the position 3 to the position 4, the piston H has to be dragged up to the top of the cylinder. Finally, whilst the crank moves from the position 4 to the position 1, the pressure of the air forces down the piston of the open cylinder. Thus all the power consumed in dragging up the piston against the pressure of the atmosphere, whilst the crank moves from 1 to 2 and from 3 to 4, is faithfully given out to the wheel whilst the crank moves from 2 to 3 and from 4 to 1. By this arrangement the engine is made to lay up, as it were, a store of power when the moving force is acting with greatest energy, and this store is employed to assist it when the moving force is acting with least energy. The pressure of the atmosphere is very adroitly converted into a sort of reservoir, in which is deposited the surplus power generated while the crank moves from 1 to 2, and from 3 to 4, to be withdrawn in order to supply the deficiency whilst the crank moves from 2 to 3 and from 4 to 1. Let A denote the number of square inches in the piston H, and *h* the number of feet in the diameter of the small wheel; then the power necessary to drag the small piston from the bottom of the cylinder to the top, exclusive of the friction, is represented by a mechanical effect of 15 × A × *h* lb. raised one foot high. Hence, the total effect of this pneumatic pump is equivalent to causing the engine to raise 15 × A × *h* lb. one foot high whilst the crank is passing the quadrantal points, and allowing that weight to fall whilst the crank is passing the line of the centres. At the first consideration we may perhaps infer that there would be a sudden change of velocity and pressure when the small piston had arrived at the top or the bottom of its stroke; but a little more

Fig. 178.



BUCKLE'S PNEUMATIC EQUALISER.

attention will convince us that the change is gradually introduced by the peculiar relation of the wheels to one another. In the position represented in the figure, the crank moves a certain distance past position 1 without raising the piston to any great extent. As the crank descends to the quadrantal point, in which position most power is generated, the crank of the small wheel descends to its quadrantal point, in which position the pressure of the atmosphere on the piston H, offers the greatest resistance to the motion of the wheel. After the large crank has passed its quadrantal point, the energy of the moving power begins to lessen, and at the same time, the small crank having passed its quadrantal point, the motion of the small wheel is less retarded by the pressure of the atmosphere on the piston H. When the large crank approaches to the position 2., the small crank approaches to the lowest part of its revolution, where the pressure of the atmosphere on the piston H, offers little opposition to the motion of the small wheel. It is unnecessary to examine the action of the pump throughout the whole revolution of the wheel, as it would be only a repetition of the process for a quadrant. But we see that, by the peculiar connection of the wheel, the pressure of the atmosphere acts at one time as an accelerating force, at another as a retarding force; that the change is not abrupt, but gradual; that it acts most efficiently as a retarding force at the very moment that the energy of the moving force is greatest, viz., when the large crank is passing the quadrantal points; and finally, it acts most efficiently as an accelerating force at the very moment that the energy of the moving force is least, viz., when the crank is passing the line of the centres. In fact, this pneumatic equaliser approaches more closely to theoretical perfection, than any expedient ever proposed for equalising the action of the engine. It may easily be shown that the equalisation of the effective pressure on the shafts is more efficient than that obtained by using a pair of engines, and certainly it is much less complicated and expensive. The superiority is still more manifest when we consider the regularity of velocity which it in practice has been known to introduce. The principal objection against the expedient is that the toothed wheels are very bad constructive expedients, as they cause considerable friction, and the teeth are apt to break and to throw the whole into disarrangement. But it is obviously not impossible to obtain the same result by a different mechanism. All that is essential is, that the shaft on which the small wheel is placed, should make two revolutions for each revolution of the main shaft. Can this only be effected by the clumsy expedient of two toothed wheels working into one another? Several ingenious expedients have been proposed for enabling one shaft performing a certain number of revolutions per minute to drive another shaft so as to make more revolutions per minute without connecting them together by tooth gearing; but it would take up too much of our space to describe them here. We may only refer to one which is applied in Smith's direct action engine, a plate of which we have given in this work. This expedient enables the main shaft to drive a second shaft with a double velocity; the very thing which is required for Buckle's pneumatic equaliser. We may remark that expedients for multiplying velocity are invested with additional interest at present, from the introduction of the screw propeller. Before a sufficiency of resistance can be obtained from the screw propeller, it must be made to perform more revolutions per minute than the paddle-shaft, in the more common construction. This new problem is at present exercising the ingenuity of many of our engineers.

To demonstrate the practical efficiency of Buckle's equaliser, we may instance the great success which has attended its application. The following is Mr. Scott Russell's description of the circumstances which first led to its adoption, and the complete success with which it was crowned:—"Mr. Lucy had constructed at Birmingham a flour-mill driven by steam, and it had been his object to obtain perfection without any limitation of expense. He had got one of Boulton and Watt's best steam engines, and yet he found that his mill neither produced such perfect flour nor moved so smoothly as mills driven by water. On the contrary, it was found that the irregularity of the motion produced a larger quantity of coarse than of fine flour, at a mercantile loss to the owner; and it was likewise found that the irregular propulsion *à tergo* interfering with the uniform motion, towards which the millstones tended by their own momentum, produced a clanging reciprocation along the whole line of toothed gearing, which was most injurious, and rapidly destructive to the toothed wheels. When we visited the spot in 1838, the ruins of former wheels, most unequally worn and totally destroyed, were strewn about the yard. The usual plan of increasing the weight of the fly-wheel was resorted to without success, and Mr. Lucy applied to Mr. Buckle to propose a remedy for the evil. This remedy Mr. Buckle found in the very simple contrivance of a pneumatic pump. In the mint at Soho a pneumatic pump had been introduced by Mr. Watt, for the purpose of producing a reaction, on the principle of the experiments of Otto Guericke, which we have already described. The force of the steam engine was made to draw up a piston from the bottom of a cylinder, leaving a vacuum below it. Into this vacuum the piston was again carried down, after the action of the steam had ceased, by the whole force of the atmosphere, amounting to about 15lbs. on every inch of its surface. Thus the atmosphere was rendered a reservoir of power, the power being first of all taken up by forming the vacuum, and again given out by the atmosphere pressing the piston down into the vacuum. So perfect was the action of this mechanism that the fly-wheel had been wholly removed, and the engine and the whole mill-work were moving in the most smooth and effective manner. It was found that the change enabled them to give all the grinding stones a greater velocity than formerly, so that the quantity ground was greater, in the proportion of 56 to 52, and the quantity of the finest or first flour, from the same wheat, was likewise much increased; so that, both by quantity and quality, the owner of the mill was now able to *command the market*. The same motion has subsequently been applied to cotton mills with perfect success, the quality and the quantity of yarn produced being much improved."

The last expedient for equalising the action of the steam which we shall notice, is that known as the fly-wheel. The fly-wheel derives all its efficacy as an equaliser of the action of the steam from the principle, that a large mass of matter offers great resistance to a change of motion. In a common double-action engine, the steam loses all energy as a moving power for driving the machinery when the crank is passing the line of the centres, and a person not familiar with the laws of matter might conclude that the engine would come to a stand-still, unless some moving force were applied at these critical positions. It is well known, however, that the momentum of the moving parts of the machinery will supply a force sufficient to force the crank over the centre, although with a diminished velocity. The momentum of the moving parts acts therefore to a certain extent as a regulator of the action of the steam, and the addition of the fly-wheel only promotes regularity of velocity in so far as it increases this momentum. The moving force of a body in motion is estimated by the product of its mass into its velocity. If, therefore, we wish to regulate the velocity of an engine, by increasing the momentum of its moving parts, we have only to connect with it some large mass that it moves with great velocity. Such a mass is the fly-wheel: it is made of large diameter, so that its rim revolves with great rapidity; and the rim is made of great weight, it being generally constructed of cast iron. It is obvious that the same amount of momentum may be obtained by other forms of construction; but the wheel possesses three advantages peculiar to itself, which entitle it to the preference: it consumes no power by friction; it suffers but little resistance to its motion from the air; and, finally, it can be so exactly poised on its axis as to cause little strain on the machinery.

When the piston is at half-stroke, the energy of the moving force is at its maximum, so that at this time more mechanical effect is generated than the usual resistance can appropriate. The surplus mechanical effect is expended in quickening the velocity of all the moving parts of the machinery. But the greater the mass of a moving body, the more opposition does it offer to a change of motion; so that the large mass of the fly-wheel absorbs the surplus mechanical effect without any great change of velocity. As the crank approaches the dead points, the effect of the moving power upon the axle and the wheel is gradually enfeebled. The defect can only be supplied by abstracting some of the momentum of the moving parts, and in these circumstances the large mass of the fly-wheel can give out the sufficient quantity of momentum without any considerable change of velocity. The mass of the fly-wheel is thus converted into a reservoir for receiving the surplus power at one time, and giving it out at another. It is obvious, however, that the equalisation of the motion produced by the fly-wheel is partial, and can never be theoretically perfect. The fly-wheel acts as a receptacle of momentum, and as matter can only receive momentum or give out momentum by a change of velocity, its agency as an equaliser presupposes a slight change in the velocity of all the machinery. The motion of revolution received by the main shaft is always subject to a variation corresponding to the amount of change of momentum in the great mass of the fly-wheel sufficient to extricate the crank twice in every revolution from its critical position while passing the line of centres; but this change can be rendered smaller and smaller by increasing the weight and magnitude of the fly-wheel. Buckle's Pneumatic Equaliser acts upon the principle of increasing or diminishing the resistance according as the energy of the moving force increases or diminishes; the fly-wheel, on the other hand, acts upon the principle of increasing the momentum of the moving parts of the machinery, so that when the energy of the moving force is greater or less than the resistance, the surplus may be absorbed or the defect supplied without any sensible change in the motion of the whole. The former is capable of theoretical perfection; the latter must necessarily fall short of that perfection, though it may be made sufficiently near it for practicable purposes.

We proceed now to mention the considerations upon which we have founded the rule given in page 157 for proportioning the size of the fly-wheel to the length of stroke and the diameter of the cylinder of the engine. It is to be remembered that in proportioning a fly-wheel to a given engine, attention must be paid to many particular circumstances which we have neglected in the general rule. Attention must be paid, for instance, to the degree of regularity which the particular application of the engine requires; for although uniformity is always desirable, it is of much greater importance in some cases than in others. Again, the efficacy of the fly-wheel in producing uniformity of velocity is materially modified by the nature of the machinery which the engine is employed to drive. If the machinery consist of large masses in revolution, such as the millstones in a flour-mill, the agency of the fly-wheel will not be so much needed, as these masses will tend to uniformity of revolution by their own momentum. In fact, properly to proportion the fly-wheel, we ought to have regard not only to the momentum of the fly-wheel, but also to the momentum of the other moving parts of the machinery. But the latter cannot be attended to in a general rule, which can only give the proportions of the fly-wheel such that, although different engines are employed to drive the same sort of machinery, the same degree of equalisation will be obtained. It is obvious that the proportion between the power which is generated in the cylinder during one half-stroke, and the power which must be resident in the fly-wheel to constitute it an equaliser, ought to be the same in engines of all sizes, in order to produce the same approximation to uniformity of motion. For although the energy of the moving force varies, still, when the engine is making the usual number of strokes per minute, the total mechanical effect generated during one half-stroke is exactly equal to the mechanical effect consumed during the same time by the resistance offered to the machinery, and by the friction of the different moving parts; and therefore the fly-wheel has only to do with the amount of variation, which, in engines of the same construction, has always a constant ratio to the mechanical effect generated during one half-stroke. Before, however, we can compare the power resident in a fly-wheel with the power generated during one half-stroke of the engine, we must have some way of estimating the amount of power treasured up in a moving body when we know its mass and velocity. It is familiar to the observation of every one, that it requires the exertion of some force, either to bring a body at rest to a state of motion, or to reduce a body in motion to a state of rest. All writers on mechanics state the following general law, founding it upon observation:—"Matter never changes its state of rest, or its state of motion, without the exertion of some extraneous force upon it." A ball in motion has in itself a certain moving energy, which, on the application of the proper machinery, can be extracted from it, and made to produce a useful effect. This moving energy has been put into the ball by some extraneous agent; and it would continue in the ball for ever, or at least as long as the present laws of matter exist, unless some extraneous force, such as the resistance of the air, be applied to extract it. It is to be remarked, also, that it requires the exertion of as much power to reduce the body in motion to a state of rest, as it did to bring it from a state of rest to its present state of motion. It is found from observation, that if two balls moving in opposite directions impinge against one another, they will be brought to rest if their weights or masses be inversely as the velocities with which they move; or, in other words, if the product of the weight of one of the balls into its velocity be equal to the product of the weight of the other ball into its velocity. It is this product which scientific writers understand by the term *momentum*. For our present purpose, however, it is necessary to estimate the moving energy of a body in motion by the mechanical effect which it can produce, or the number of pounds which it can raise one foot high. This is a more tangible standard of measurement, and will be more easily apprehended by those who are familiar with a similar method of estimating the power of a horse, or of a certain quantity of steam. With reference to this standard we now proceed to prove the following proposition:—

A body of P lb. weight, moving with a velocity of v feet per second, has a moving energy whose mechanical effect is $P \times (v \div 8)^2$ *lb. raised* 1 *foot high.*

For, let h denote the height in feet through which the body has to fall in order to acquire the velocity v, by the action of gravity. Then we know, from the laws of falling bodies, that $h = v^2 \div 64 = (v \div 8)^2$, and the ball will have a mechanical effect treasured up in it $= \mathrm{P} \times h = \mathrm{P} \times (v \div 8)^2$ lb. raised one foot high. Now, as the moving ball will possess the same amount of energy however the velocity is acquired, it is obvious that, in general, a ball of P lb. weight, moving at the rate of v feet per second, has treasured up in it a mechanical effect of a $P \times (v \div 8)^2$ lb. raised one foot high.

Example 1. Required the mechanical effect treasured up in a ball of 30 lb. weight moving at the rate of 12 feet per second.

In this case the mechanical effect treasured up in the ball $= 30 \times (12 \div 8)^2 = 67\frac{1}{2}$ lb raised one foot high.

Example 2. Required the mechanical effect treasured up in a cast-iron fly-wheel, whose mean diameter is 30 feet, sectional area of rim 60 square inches and making 20 revolutions per minute.

Before solving this, it will be necessary to calculate the velocity of the rim in feet per second. The diameter of the wheel being 30 feet, the circumference of the wheel $= \pi \times 30 = 94{\cdot}248$ feet; and as the wheel makes 20 revolutions per minute, the velocity of the rim $= 94{\cdot}248 \times 20 = 1884{\cdot}96$ feet per minute. Hence v = velocity of the rim in feet per second $= 1884{\cdot}96 \div 60 = 31{\cdot}416$. Again, the cubical content of the rim = sectional area × circumference $= 60 \times 94{\cdot}248 \div 144 = 5 \times 94{\cdot}248 \div 12 = 5 \times 7{\cdot}854 = 39{\cdot}27$ cubic feet, and the weight of a cubic foot of cast iron = weight of cubic foot of water × specific gravity $= 62\frac{1}{2} \times 7\frac{1}{4} = 453\frac{1}{8}$ lb.; so that the weight of the rim $= 39{\cdot}27 \times 453\frac{1}{8}$ lb. $= 17794{\cdot}22$ lb. Hence the mechanical effect treasured up in this fly-wheel $= 17794{\cdot}{\cdot}22 \times (31{\cdot}416 \div 8)^2 = 17794{\cdot}22 \times (3{\cdot}927)^2 = 17794{\cdot}22 \times 15{\cdot}42 = 274386{\cdot}87$ lb. raised 1 foot high. The nominal horse-power of an engine represents a mechanical effect of 33,000 lb. raised 1 foot high per minute, so that this fly-wheel possesses within itself more mechanical effect than is expended by an engine of eight-horse power upon its resistance for one minute. This is entirely independent of the mechanical effect treasured up in the arms of the fly-wheel, and in the other moving parts of the machinery.

In a common double-action engine constructed on Watt's principle, the effective pressure of the steam on the piston is about 7 lb. per square inch. Hence, if S = length of stroke in feet, D = diameter of cylinder in inches, and m = ratio of the average mechanical effect treasured up in the fly-wheel to the mechanical effect generated during one half-stroke, then the total mechanical effect usually resident in the fly-wheel $= 7 \times \frac{\pi}{4} \times m \times \mathrm{D}^2 \times \frac{\mathrm{S}}{2} = 7\,\pi\, m\, \mathrm{D}^2\, \mathrm{S} \div 8$ lb. raised one foot high; and for any particular case, we must determine the sectional area so that for a given diameter of fly-wheel, and for a given number of revolutions, the average mechanical effect shall equal this. In practice, the average speed of the piston $= 128\sqrt[3]{\mathrm{S}}$ feet per minute, and therefore, if the fly-wheel makes one revolution for each double stroke of the engine, the number of revolutions per minute $= 128\sqrt[3]{\mathrm{S}} \div 2\,\mathrm{S} = 64 \div \mathrm{S}^{\frac{2}{3}}$; but if the fly-wheel makes n revolutions for each double stroke of the engine, the number of revolutions per minute $= 64\, n \div \mathrm{S}^{\frac{2}{3}}$. Let d denote the diameter of the fly-wheel in feet. Then the circumference $= \pi d$, and the velocity in feet per minute $= \pi d \times 64\, n \div \mathrm{S}^{\frac{2}{3}}$, and the velocity in feet per second $= 1{\cdot}06\, n \pi d \div \mathrm{S}^{\frac{2}{3}}$. Let now A = area of the rim in square inches, and δ = the specific gravity of the body as compared with water. Then the content of the rim in cubic feet $= \pi d\, \mathrm{A} \div 144$; and the weight of the rim in lbs. $= \pi\, d\, \delta\, \mathrm{A} \times$ weight of a cubic foot of water in lb. $\div 144 = \pi d \delta \mathrm{A} \times 62\frac{1}{2} \div 144 = \pi\, d\, \delta\, \mathrm{A} \times {\cdot}434$. Hence the mechanical effect in lbs. raised one foot high $= \pi\, d\, \delta\, \mathrm{A} \times {\cdot}434 \times (v \div 8)^2 = \pi d \delta \mathrm{A} \times {\cdot}434 \times ({\cdot}13\, n \pi d \div \mathrm{S}^{\frac{2}{3}})^2 = {\cdot}00771\; n^2 \pi^3\, \delta\, d^3 \mathrm{A} \div \mathrm{S}^{\frac{4}{3}}$. So that, to determine A, we have the equation

$$\frac{{\cdot}00771\, n^2 \pi^3 \delta d^3 \mathrm{A}}{\mathrm{S}^{\frac{4}{3}}} = \frac{7\,\pi\, m\, \mathrm{D}^2 \mathrm{S}}{8};$$

or,

$${\cdot}06168 \times n^2 \pi^2 \delta d^3 \mathrm{A} = 7\, m\, \mathrm{D}^2 \mathrm{S}^{\frac{7}{3}};$$

or,

$${\cdot}00881\, n^2 \pi^2 \delta d^3 \mathrm{A} = m\, \mathrm{D}^2 \mathrm{S}^2 \times \sqrt[3]{\mathrm{S}};$$

or, substituting the value of $\pi^2 = (3{\cdot}1416)^2 = 9{\cdot}8696$,

$${\cdot}0869\, n^2 \delta d^3 \mathrm{A} = m\, \mathrm{D}^2 \mathrm{S}^2 \times \sqrt[3]{\mathrm{S}};$$

and therefore,

$$\mathrm{A} = \frac{{\cdot}n}{{\cdot}0869\, n^2 \delta} \times \frac{\mathrm{D}^2 \mathrm{S}^2 \times \sqrt[3]{\mathrm{S}}}{d^3}$$

$$= 11{\cdot}507 \times \frac{m}{n^2 \delta} \times \frac{\mathrm{D}^2 \mathrm{S}^2 \times \sqrt[3]{\mathrm{S}}}{d^3}.$$

In this equation the number denoted by m remains to be determined. As we said previously, this number regulates the degree of uniformity of velocity obtained by the action of the fly-wheel. Some theoretical considerations might here be advanced, which might enable us to estimate the value of m corresponding to any particular amount of variation of velocity. Supposing that we knew the law according to which the pressure on the piston, and the velocity of the piston, at different parts of the stroke, vary, we should have to calculate how much surplus power is generated during the favourable circumstances, and the deficiency of power generated during the unfavourable circumstances, and then inquire what must be the value of m, in order that the storing up of the surplus power in the fly-wheel rim at one time, and the withdrawing of that power to supply the deficiency at another time, would cause the velocity to vary only within the proposed limits. This could easily be solved if we neglected the variation of resistance consequent upon a variation of velocity, and knew accurately the law according to which the pressure on the piston and its velocity vary. Instead of this, however, we propose to determine m entirely from practice. Indeed, the dimensions of fly-wheels which will have energy enough to produce a sufficiently regular motion for the purposes of manufactories, has been determined by long experience, more decisively than could be done by theory. It will be found by observation of engines of all sizes, that the energy of the rim of the fly-wheel is usually between three and four times the power generated during half a stroke. In other words, if the engine were only employed to give motion to the fly-wheel rim, and had not to overcome some uniform resistance, it would require between three and four half-strokes of the piston to urge the wheel from its state of rest to the state of uniform motion with its average velocity. In engines working in conjunction, so that their cranks are at right angles, a smaller fly-wheel than usual will suffice; and in many of the engines manufactured by Mr. Fairbairn, of Manchester, and others, a heavy spur-wheel on the crank shaft is the only fly-wheel employed. In engines, too, working at a very high speed—and land engines may be made to work at twice the usual speed with advantage—a very small fly-wheel will answer, or in the case of coupled engines driving millstones or other large masses of matter in rapid rotation, or in the case of single engines provided with a pneumatic equalizer, it may be dispensed with all together. If the speed of an engine be doubled, a fly-wheel of one fourth of the ordinary weight will produce the same effect as a common fly-wheel with the engine moving at the usual velocity. We here subjoin some standard examples of Boulton and Watt's engine, which show that m, or the proportion between the energy of the rim of the fly-wheel and the power exerted by the piston during one half-stroke, even in those engines varies considerably

STANDARD EXAMPLES OF BOULTON AND WATT'S ENGINES.

Where employed.	D.	S.	Horse Power.	Number of Revolutions of Fly-wheel Shaft.	Value of m.
Starch manufactory at Lambeth, in London	17½	4	10·34	48½	3·13
Dye-house, in London	17½	4	10·34	48½	3·40
Dye-house in Southwark, near London Bridge, London.	24	5	20·95	42	4·16
Machinery at a public work in London, employed to turn eight pairs of rolling-stones.	24	5	20·95	21	2·60
Cotton-spinning mill, at Manchester	28½	6	30·36	19	2·67
Iron Work in Staffordshire, for rolling out iron into bars.	31½	7	40·38	35	3·14
Employed at the Albion Flour Mills [Each of the axes of the fly-wheels worked five pairs of mill-stones. The value of *m* for these stones was 2·9]	34	8	49·19	- -	2·77
Distillery on the banks of the Thames	36	7	52·75	- -	3·06

It will be observed that the value of *m* varies, in these examples, from the minimum value, 2·6, to the maximum value, 4·16. It may be observed, also, that the value of *m* depends upon the nature of the machinery which the engine has to drive. Thus when the engine is employed to drive large rolling-stones, the value of *m* is only 2·6, for these stones act of themselves as fly-wheels. At the Albion flour-mills, where each shaft had to drive five pairs of mill-stones, the value of *m* was 2·77; but it was found, upon calculation, that these mill-stones acted as efficiently of themselves as a fly-wheel for which $m=2·9$; so that the effective value of $m=2·77+2·9=5·67$. The largest value of *m* in these examples is 4·16, which obtains in the engine erected by Boulton and Watt at a dye-house in London. This large value was necessary because the machinery driven had very little momentum of its own, and because in that case great regularity of velocity was considered necessary. In the preceding examples the mean value of *m* is 3·12. For more modern examples the average value of *m* is greater. Perhaps the average value of *m* for modern engines is $3·5=3\frac{1}{2}$. We shall take $m=3\frac{3}{4}$; for we think it better to err in excess than in defect. For this value the equation becomes

$$A=\frac{43·151}{n^2\delta}\times\frac{D^2S^3\times\sqrt[3]{S}}{d^3}.$$

The constant δ has different values for different materials:

for malleable iron $\delta=$ 7·63.
for cast iron $\delta=$ 7·05.

And for these different values our equation becomes, successively

$$A=\frac{5·65}{n^2}\times\frac{D^2S^3\times\sqrt[3]{S}}{d^3}\text{, for malleable iron,}$$

$$A=\frac{6·125}{n^2}\times\frac{D^2S^3\times\sqrt[3]{S}}{d^3}\text{, for cast iron}$$

In general the fly-wheel makes one revolution for each double stroke of the engine, so that $n=1$. Taking this value of *n*, it will be seen that the formula for the sectional area of rim, when constructed of cast iron, is identical with the rule given for the same purpose in page 157.

Fly-wheels are sometimes employed for other purposes than merely regulating the velocity of the steam-engine. Whenever the employment of an engine is such that an enormous force is required to act only for short times, such as when it is employed for rolling iron, or for stamping coins, then an enormous fly-wheel is attached to the engine, which absorbs the power generated when the resistance is removed, and gives it all the force at once at the proper moment. In these cases, the mass of the fly-wheel rim is generally much greater than when the fly-wheel is only employed to regulate the velocity, in order that the momenta may be accumulated without inconveniently increasing the velocity. In some cases the value of *m* is as great as 50; so that the energy of the fly-wheel would be $(50\div3\frac{3}{4}=13)$ thirteen times greater than what the proportions given by our rule would make it. Fly-wheels moving at a great velocity should always have malleable iron arms, and the ring should be cast in a piece, and may be hooped with malleable iron with advantage.

EXPEDIENTS FOR REDRESSING THE INEQUALITIES OF VELOCITY ARISING FROM THE VARIATION OF RESISTANCE WHICH THE ENGINE HAS TO OVERCOME.

By the expedients which we have mentioned for equalising the velocity of the engine, the motion imparted to the main shaft will approximate to uniformity, provided that the moving power of the engine be always proportionate to the load which the engine has to drive. But it is obvious that in the general application of the steam engine to the purposes of manufacture, provision must be made for a considerable variation of the amount of resistance. If, while the amount of resistance was changed, the energy of the moving power remained the same, then the velocity would also change, increasing as the resistance diminished, and diminishing as the resistance increased. It is obvious that an expedient for redressing the inequalities arising from this source may act upon the principle of regulating the supply of steam from the boiler. The elastic force of the steam is the moving agent of the whole machine; so that if we wish to keep the mean velocity constant, we must regulate the supply of steam to the amount of resistance to be overcome. The simplest contrivance for this purpose is represented in *fig.* 22, at page 18. of this work. This contrivance is well known under the title of the THROTTLE VALVE; so called from its agency in cutting off the supply of steam by throttling it in the steam pipe. It consists of an axis placed across the steam pipe so as to form the diameter of a section of the pipe, and on this axis is fixed a thin circular disc Z, of nearly the same diameter as the inside diameter of the steam pipe; so that when the axis is turned to a certain position, the supply of steam is cut off altogether. On one end of the axis is placed a short lever or handle Zw, by which it can be turned in either direction. When the handle is turned so that the plane of the disc is nearly at right angles to the direction of the steam pipe, the passage within the pipe is closed altogether, and no steam can find admission to the cylinder. On the other hand, when the handle is turned about a fourth of a complete revolution from this position, the plane of the circular disc will then be in the direction of the length of the pipe, so as to offer little or no opposition to the passage of the steam. By turning the handle to any other angle, the disc may be made to offer any required degree of opposition to the passage of the steam. In the woodcuts referred to the valve is represented in an intermediate position betwixt its position when the steam is cut off entirely, and its position when the steam is allowed to pass freely. A view of the valve as seen by a section of the steam pipe, is represented in one of the parts of *fig.* 22., and a section of it through the axis of the steam pipe is represented in the other. The form of the valve is obviously such that, if constructed accurately, the pressure of the steam in passing from the boiler will have no tendency to change any given position of the valve. If constructed accurately, the quantity of surface on both sides of the axis is equal, and therefore the pressure of the steam balances itself on the axis, so that it can have no tendency either to change the valve from its existing position, or to oppose the effect of a pressure upon the handle. Any slight inaccuracy in the construction of the valve, which would give the steam a capability of changing its position, would be counteracted by the friction of the valve on its axis.

By this expedient the variations of the velocity of the engine, consequent upon the inequalities of resistance which the engine has to overcome, may be remedied. If the load on the engine be lightened, then, the supply of the steam continuing the same, the motion will be immediately accelerated, but the tendency will be counteracted if the attendant workman turn round the handle, so as partially to close the valve. If, on the other hand, the load on the engine be increased, then, the supply of the steam continuing the same, the motion will be immediately retarded. To counteract this, the attendant workman must turn round the valve, so as to admit a greater supply of steam. By the adoption of these means the mean velocity of the engine would be rendered uniform, provided the vigilance of the attendant workman were sufficient for the due management of the valve, and provided that the evaporating power of the boiler continued in sufficient activity to supply the greatest amount of steam which would ever be necessary for the maintenance of the mean velocity when the valve was fully open.

For some purposes engines are thus regulated by hand at the pleasure of the attendant workman. In general, however, the proper manipulation of the handle is impracticable with any degree of vigilance and skill which could be obtained from the persons employed to attend the engine. Before the steam engine could be employed in those cases where great uniformity of velocity is required, it was necessary that means should be found for enabling the engine itself properly to manipulate the valve without any care or attention on the part of the attendant workman. Watt, after trying several expedients, fixed upon the conical pendulum or governor as the best adapted for this purpose, the principle of which has already been explained at page 18.

THE GOVERNOR.

In the mechanism of the governor as represented in *fig.* 23., E E represent two heavy balls of iron, which are suspended from the point *e* by suitable arms. These bars cross one another at *e*, forming a joint there, and are continued to *f*. At *f* these bars are joined by pivots to other bars *fh*, which last fit into a ring or collar of metal at F, placed on the upright spindle, so as to be capable of a motion upwards and downwards. The lever F G H rests upon a bar at G as fulcrum, and is connected to the ring of metal at F by means of a forked end interposed between two collars on the sliding piece. In this species of connection it is obvious that the ring of metal may revolve with the spindle without moving the lever, but that it cannot move upwards or downwards on the spindle without at the same time depressing or raising the remote extremity, H, of the lever. The bars E*ef* pass through slits in a metallic arch, which is firmly fixed to the upright spindle, so that the balls, the arms, and the spindle must all revolve at the same time. If, now, the spindle be made in any manner whatever to revolve with a certain velocity, say thirty revolutions per minute, the balls E E will diverge from the spindle till their centrifugal force balances their weight. Let this be the position represented in the figure. If the spindle be made to make more revolutions than 30, then the balls will diverge more than what is represented in the figure. The points *f f* will diverge, and by means of the bars *f h* pull down the one end F of the lever F H, and raise the other end H. This, by the mechanism represented in the figure, would obviously tend to shut the valve, and to cut off the supply of steam. If, on the other hand, the spindle be made to perform fewer revolutions per minute than 30, the balls will collapse more than what is represented in the figure. The points *f f* will approach to one another, and by means of the arms *f h* force up one end F of the lever, and depress the other end H. This will obviously tend to open the valve, and to increase the supply of steam. After this action is understood, it is not difficult to see how this expedient may be advantageously employed to regulate the velocity of the engine. Suppose that by some mechanism or other the upright spindle is so connected with some moving part of the machinery, that when the velocity of the engine is unduly accelerated, the spindle performs more than 30 revolutions, and that when the velocity of the engine is unduly retarded, the spindle performs less than 30 revolutions per minute, then this expedient becomes a regulator of all the inequalities of velocity arising from the variations in the amount of resistance to be overcome. The upright spindle may be connected with the fly-wheel shaft by means of an endless cord passing over a small grooved wheel *d* on the axis of the spindle, and working into a similar groove on the fly-wheel shaft, or by gearing, which is a preferable mode in large engines. By properly proportioning the diameters of these wheels, the spindle may be made to perform any number of revolutions per minute. It is obvious, that by these means the speed of the grooved wheel *d* may be considered as representing the speed of the fly-wheel, and of the machinery which the fly-wheel drives. After these observations, and the remarks upon the subject we have already made at page 34, the principle which renders the governor so admirable a regulator of the velocity of the machine will be easily apprehended. Let t denote the time in seconds of a periodic revolution of the balls, and h the height in inches of e above the horizontal plane passing through the centre of the balls; then, according to the formula which we have given in page 34,—

$$t = {\cdot}31986\sqrt{h}$$

Let n denote the number of revolutions per minute, then we have the proportion—

$${\cdot}31986\sqrt{h} : 60 :: 1 : n = \frac{60}{{\cdot}31986\sqrt{h}}$$

or $n = 187{\cdot}58 + \sqrt{h}$, which also may be written $h = 35186 \div n^2$. We have supposed *fig.* 23., page 18., to represent the divergence of the balls when the spindle was making 30 revolutions per minute. In that case $n = 30$, and $h = 35186 \div 30^2 = 35186 \div 900 = 39{\cdot}09$ inches, or about $39\frac{1}{10}$ inches. Now suppose that the velocity of the engine was accelerated so much that the spindle performed 31 revolutions per minute; then, taking $n = 31$, we obtain $h = 35186 \div 31^2 = 35186 \div 961 = 36{\cdot}61$ inches, or somewhat more than $36\frac{1}{2}$ inches. Thus, before the spindle can perform one more revolution per minute, the plane of revolution of the balls rises $39\frac{1}{10} - 36\frac{6}{10} = 2\frac{5}{10} = 2\frac{1}{2}$ inches, which obviously would cause a very great change in the angle of divergence of the arms E*ef*. Suppose, on the other hand, that the velocity of the engine were retarded so much that the spindle performed only 29 revolutions per minute. Then, by taking $n = 29$, we find $h = 35186 \div 29^2 = 35186 \div 841 = 41{\cdot}84$ inches, or between $41\frac{3}{4}$ and 42 inches. Thus before the spindle can perform one less revolution per minute, the plane of revolution of the balls must fall $41{\cdot}84 - 39{\cdot}1 = 2{\cdot}74 = 2\frac{3}{4}$ inches nearly, which would obviously cause the angle of divergence of the arms E*e* to diminish very considerably. The efficiency of the governor in regulating the supply of steam depends very much upon the mechanism employed to communicate its agency to the throttle-valve. We may suppose the relations of the different bars E*ef*, *fh*, F G H, and H*w*, to be such, that when the horizontal plane passing through the centre of the two balls E E is only 36·61 inches below the point of suspension *e*, the throttle-valve would entirely close up the steam-pipe, and that when the horizontal plane passing through the centres of the two balls E E is 41·84 inches below the point of suspension *e*, the throttle-valve would be fully open. On this supposition the effect of the governor would be, that the engine could never be so much retarded as that the upright spindle performed less than 29 revolutions per minute, or so much accelerated that the upright spindle performed more than 31 revolutions per minute. This would ensure that the greatest change of velocity of any part of the machinery could never exceed $\frac{2}{30} = \frac{1}{15}$ of its mean velocity,—a variation which in practice is scarcely perceptible; so that such a governor might be considered as practically perfect. In the best modern engines the amount of variation is seldom less than one-tenth of the mean velocity. But we may easily suppose the governor to be so connected with the engine as to act with even greater efficiency than the one which we have described. The governor can be so proportioned, and so connected with the engine, as to make 60 revolutions per minute; and the mechanism connecting it with the throttle-valve may be so contrived, that when it makes 59 revolutions per minute the valve may be fully open, and that when it makes 61 revolutions per minute the valve may entirely closed. In this case the greatest variation of the velocity of any part could never exceed one-thirtieth of the mean velocity of that part. Indeed in theory there is no limitation to the degree of regularity which may be produced by the application of the governor. Practical considerations, however, limit the application of the principle in several ways. It has been found inconvenient, for example, to allow minute alterations of the governor to affect sensibly the position of the valve, and in order to prevent the inconvenience arising from a continual changing in its position it is found expedient to construct the governor such that even a considerable change in the divergence of the balls shall not produce too much alteration in the opening of the valve. This consideration, and several others, limit the application of the governing principle, and prevent engineers from approximating so closely to theoretical perfection, as the principle permits.

In the construction of a governor to regulate a particular engine, it is necessary to consider the position of the balls corresponding to the mean velocity of the engine, the range of motion which must be given to the arms so as to enable them to confine the variations of velocity within certain limits, and the weight of each of the balls. We proceed to consider each of these points separately.

POSITION OF BALLS WHEN MOVING WITH MEAN VELOCITY.

To determine this position, we have only to consider the vertical height of the point of suspension above the horizontal plane passing through the centre of the balls when the spindle is making the average number of revolutions per minute. This is found from the formula

$$h = \frac{35186}{n^2}$$

From which we have the following rule:—

Rule.—*To determine the height of the point of suspension above the plane of the balls, when moving with mean velocity.—Divide the number* 35186 *by the square of the mean number of revolutions per minute. The quotient is the height of the point of suspension above the plane of the balls when moving with mean velocity.*

Example 1.—In a particular engine the governor is so connected with the fly-wheel shaft, that when the engine is moving with average velocity the upright spindle makes 40 revolutions per minute. Required the proper height of the point of suspension above the plane of the balls.

In this example—

$$h = \frac{35186}{40^2} = \frac{35186}{1600}$$

$$= \frac{351{\cdot}86}{16} = 21{\cdot}99 \text{ inches.}$$

so that the proper height is about 22 inches.

Example 2.—The governor spindle is driven by the fly-wheel shaft by means of an endless cord passing over a groove on the spindle, and another groove on the fly-wheel shaft. The diameter of the groove on the governor spindle is 9 inches, and the diameter of the groove on the fly-wheel shaft is 12 inches. The engine has a stroke of 8 feet, and the mean velocity of the piston is 256 feet per minute. Required the proper height of the point of suspension above the plane of the balls.

In this example, since the mean velocity of the piston is 256 feet per minute, and the length of the stroke 8 feet, it follows that the engine makes $256 \div 8 = 32$ single strokes, or 16 double strokes per minute. The fly-wheel makes one revolution for each double stroke of the piston, and therefore the fly-wheel also makes 16 revolutions per minute. The number of revolutions of the fly-wheel shaft is to the number of the revolutions of the governor spindle inversely as the diameters of the grooves; so that we have the proportion

$$9 : 12 :: 16 : n = \frac{16 \times 12}{9} = 21\frac{1}{3}.$$

Hence, according to the rule—

$$h = \frac{35186}{(21\frac{1}{3})^2} = \frac{35186}{455\frac{1}{9}} = 77{\cdot}31 \text{ inches.}$$

This proportion is one never employed in practice on account of the inconvenience of the dimensions; but it is that proper to the data assumed.

THE RANGE OF MOTION OF THE ARMS.

This depends entirely upon the amount of variation of velocity which may be permitted without detriment to the work upon which the engine is applied. We have already shown, that when the governor performed on an average 30 revolutions per minute, a variation of velocity equal to one-fifteenth of the mean velocity required only a range corresponding to a vertical height of 5·23 (=41·84 − 36·61) inches. But we shall now conduct the inquiry in general terms.

Let

v = mean velocity of any moving part of the machinery.

n = number of revolutions of the governor spindle corresponding to v.

h = height of point of suspension above the plane of balls corresponding to v.

$v+\frac{1}{2}mv=(1+\frac{1}{2}m)\ v=$ maximum velocity of any moving part of the machinery.

$h^1=$ value of h corresponding to $(1+\frac{1}{2}m)\ v$.

$v-\frac{1}{2}mv=\ (1-\frac{1}{2}m)\ v=$ minimum velocity of any moving part of the machinery.

$h_1=$ value of h corresponding to velocity $(1-\frac{1}{2}m)\ v$

Then we wish to find the value of h_1-h^1. It is obvious that the value of n corresponding to the maximum velocity will be $(1+\frac{1}{2}m)\,n$, and the value of n corresponding to the minimum velocity will be $(1-\frac{1}{2}m)\,n$. Hence, according to the rule,

$$h^1=\frac{35186}{1+\frac{1}{2}m)^2n^2}$$

$$h_1=\frac{35186}{(1-\frac{1}{2}m)^2n^2}$$

and therefore,

$$\begin{aligned}h_1-h^1&=\frac{35186}{(1-\frac{1}{2}m)^2n^2}-\frac{35186}{(1+\frac{1}{2}m)^2n^2}\\&=\frac{35186\times\{(1+\frac{1}{2}m)^2-(1-\frac{1}{2}m)^2\}}{(1-\frac{1}{2}m)^2\times(1+\frac{1}{2}m)^2\times n^2}\\&=\frac{35186}{n^2}\times\frac{2m}{(1-\frac{1}{4}m^2)^2}\\&=\frac{35186}{n^2}\times\frac{32m}{(4-m^2)^2}\\&=\frac{32m}{(4-m^2)^2}\times h\end{aligned}$$

This formula is too complicated to be easily expressed in the form of a rule; but its applications may easily be apprehended from the following examples.

Example 1.—The governor of a steam-engine performs 30 revolutions per minute when the engine is moving at the average speed. Required the range as expressed in vertical height of the arms of the governor, such that the difference between the maximum and minimum velocity of any moving part should never exceed one-fifteenth of the average velocity of that part.

In this example $m=\frac{1}{15}$, and as we have shown previously, $h=39{\cdot}09$.

Hence,

$$\begin{aligned}h_1-h^1&=\frac{32\times\frac{1}{15}}{\left(4-\left(\frac{1}{15}\right)^2\right)^2}\times 39{\cdot}09\text{ inches.}\\&=\frac{32\times15^3}{(4\times15^2-1)^2}\times39{\cdot}09\text{ inches.}\\&=\frac{32\times3375}{(4\times225-1)^2}\times39{\cdot}09\text{ inches.}\\&=\frac{32\times3375}{899^2}\times39{\cdot}09\text{ inches.}\\&=\frac{108000}{808201}\times39{\cdot}09\text{ inches.}\\&={\cdot}134\times39{\cdot}09\text{ inches.}\\&=5{\cdot}23\text{ inches.}\end{aligned}$$

which is the same result as formerly.

Example 2.—The governor of a steam-engine performs 21½ revolutions per minute when the engine is moving with average speed, in which case one of the shafts driven by the engine performs 80 revolutions per minute. Required the vertical range of the balls of the governor, such that this shaft should never perform more than 84 or less than 76 revolutions per minute.

In this case $m=8\div80=1\div10$, and, as we have shown formerly, $h=77{\cdot}31$.

Hence

$$\begin{aligned}h_1-h^1&=\frac{32\times\frac{1}{10}}{\left(4-\left(\frac{1}{10}\right)^2\right)^2}\times77{\cdot}31\text{ inches.}\\&=\frac{32\times10^3}{(4\times10^2-1)}^2\times77{\cdot}31\text{ inches.}\\&=\frac{32\times1000}{(400-1)^2}\times77{\cdot}31\text{ inches.}\\&=\frac{32000}{399^2}\times77{\cdot}31\text{ inches.}\\&=\frac{32000}{159201}\times77{\cdot}31\text{ inches.}\\&={\cdot}201\times77{\cdot}31\text{ inches.}\\&=15{\cdot}539\text{ inches,}\end{aligned}$$

or a little more than 15½ inches.

We may conclude these investigations respecting the governor with a summary of the most important points in the rationale of its operation. The governor may either be considered as a conical pendulum compounded of the movements of two pendulums vibrating at right angles with one another, or it may be viewed simply as a system of revolving balls, of which gravity is the centripetal force. In the former case the governor will make half the number of revolutions that a pendulum of the same vertical height makes of vibrations; and if the speed of the governor be urged beyond this point, the arms will fly out and diminish the vertical height, until it just becomes equal to the length of a pendulum that makes twice the number of vibrations in the minute that the governor makes of revolutions. Every one knows that if the length of a pendulum be diminished, it will make a greater number of vibrations in a given time than before; the cause of which simply is, that the steepness of the arc in which the ball of the pendulum descends is then increased, and it consequently descends with a greater velocity. The length of the seconds' pendulum at the level of the sea in London is 39·1393 inches, and the number of vibrations made in a given time by pendulums of different lengths varies inversely as the square roots of their lengths. The proper speed for a governor, therefore, with a vertical height of about 39 inches, is 30 revolutions per minute, which accords with the preceding determinations; and similarly if the vertical height of governor proper to any other number of revolutions be required, it is only necessary to find the length of a pendulum, which will give twice the number of vibrations, or the rule may be adopted that is given at page 34. If the number of revolutions and the length of the arm be fixed, and it is wanted to know what is the diameter of the circle described by the centre of the ball, it is necessary to find the vertical height by the foregoing rule; or the following may be adopted. Divide the constant number 187·68 by the number of revolutions per minute, and the square of the quotient will be the vertical height in inches of the centre of suspension above the plane of the ball's revolution. Deduct the square of the vertical height in inches from the square of the length of the arm in inches, and twice the square root of the remainder is the diameter of the circle in which the centres of the balls revolve. The vertical height of the governor is in every case taken as the distance between this circle and the point of suspension.

In considering the governor as a system of bodies acted upon by centrifugal and centripetal forces, the same results are obtained as where it is regarded as a conical pendulum. The horizontal distance of the ball from the spindle, divided by the vertical height, will give the amount of centripetal force; and the velocity of revolution requisite to produce an equivalent centrifugal force may be found by multiplying the centripetal force of the ball in terms of its own weight by 70·440, and dividing the product by twice the distance of the centre ball from the centre of the spindle in inches. The square root of the quotient is the right number of revolutions of the spindle per minute. Considering the question in this way, we first fix the length of the arms and the diameter of the base of the cone, or what is the same thing, the angle at which it is desired the arms may revolve; and then, by the rule given above, we make the speed of revolution such that the centrifugal force will keep the balls in the desired position. Many persons find some difficulty in considering the governor as a pendulum, inasmuch as it may be driven at *any speed;* but each particular speed has a vertical height of the centre of suspension above the plane of revolution *proper to itself*, and one condition cannot be altered without affecting the other. The method of considering the governor, however, as a revolving system of balls, does not involve this difficulty, and to many engineers it will therefore be the most satisfactory.

WEIGHT OF BALLS.

The proper weight of balls depends principally upon the nature of the mechanism employed to transmit the agency of the governor to the throttle-valve. In practice they are generally somewhere between 30 and 80 lb. each. It may be remarked in general, that of two governors performing the same number of revolutions per minute, the one which is farthest removed from its throttle-valve, and which is consequently connected with it by the most complicated mechanism, ought to have the heaviest balls. No general rule founded upon theory can be given for determining the proper weight of these balls in any particular case. In fact, according to theory the agency of the governor is altogether independent of the weight of the balls; for the balls perform the same number of revolutions per minute, and revolve at the same distance from the spindle, whatever is their weight. The truth of this remark will appear clear enough if each ball be supposed to be compounded of a number of smaller balls, each of which would certainly keep the same position as the larger ball; and every particle may therefore be supposed to act for itself. Though the centripetal force of the balls be increased, therefore, by adding to their weight, yet, inasmuch as their centrifugal force when in motion is increased in the same proportion, their position, when the governor is set into revolution, cannot be affected thereby. An increase in the weight of the balls gives the governor more power to open or close the throttle valve, but does not in any other way affect its operation. Large engines, where the valves are large and stiff, require to have the balls of the governor of corresponding size, especially if the connexions between the governor and throttle valve are stiff and complicated; but in no other respect is the size of the balls of importance.

The principle on which the governor acts, necessarily supposes temporary variations of the speed. The governor, theoretically speaking, does not maintain a uniform velocity, but restores it after it has been disturbed. Suppose that, either by reason of the diminished load upon the engine, or an increased evaporative power in the boiler, the speed of the engine is accelerated, the governor, being immediately affected, will cause a corresponding alteration in the throttle-valve; but in general, this alteration being too much, the velocity of the engine will be too much retarded. This second error will again affect the governor in the contrary way, and the speed will now be increased beyond the proper limit. Thus a succession of alternations of effect will ensue, until the governor settles down into the position corresponding to the proper speed. The agency of the governor is never brought into use before a change of velocity has taken place. The very supposition that a governor acts, presupposes that a change of the speed has ensued; and which, though it corrects, it cannot prevent from arising.

VARIETIES OF GOVERNORS.

In engines employed to pump water for the supply of towns, another expedient has been employed to produce the same effect as the governor which we have just described, which consists of a small cylinder with a piston in communication with the main pipe, through which the engine forces the water. The piston of the cylinder is loaded with a weight corresponding to the velocity with which it is wished that the engine should move, and is raised by the compressed air in the air-vessel of the pumps. When the engine is moving with an accelerated velocity, the increased pressure of the water forces up the loaded piston. When, on the other hand, the engine is moving with a retarded velocity, the diminished pressure of the water allows the loaded piston to fall. It is obvious, that by properly connecting the piston-rod of this piston with a throttle-valve in the steam-pipe, the engine would become its own regulator. This plan, so simple in theory, is attended by so many difficulties in the construction and in the practical working, that it is now universally abandoned. We may mention, that when this plan was in use, in order to prevent the piston from acting too sensibly upon the throttle-valve, it was customary to have the load divided into links like a chain; so that when the piston ascended, more links were raised, and consequently the load was increased, and when the piston descended, the links by resting on the ground diminished the load.

The principle of the preceding expedient has sometimes been employed to regulate the mean velocity of the engine, by varying the rate of expansion used. The up and down motion of the small piston is employed to adjust the tappets which shut off the steam. The motion of the small piston is communicated to a wheel which turns a pair of bevelled wheels, one of which is on the square part of a rod attached to the plug-tree. The effect of the mechanism is, that when the motion of the engine is too rapid, a rod is turned, which moves the tappet so as to cut off the steam sooner; and when, on the other hand, the motion of the engine is too slow, the tappet is moved so as to be longer in cutting off the steam. When the engine is moving at the proper rate, the tappets remained undisturbed. This plan, however ingenious it may be in conception, does not work well in practice. It wants the simplicity which characterises the action of the governor, and has long been discontinued.

The conical pendulum is the governor employed almost universally for the regulation of the speed of rotative steam-engines. Yet other kinds have been introduced, and in some instances with a good effect. One very sensitive governor consists of a cylindrical double bellows, worked by the engine, and furnished with a small cock at the orifice at which the air escapes, so that it may be contracted at pleasure. When the engine runs beyond the right speed, an additional quantity of air is taken in by the bellows, which, as it cannot obtain a free exit by the orifice contracted by the cock, raises up the superior or floating part of the bellows, to which a rod is attached that closes the throttle valve. When the speed slackens, the floating part of the bellows subsides, and opens the throttle-valve, until, after a few fluctuations, a mean point is reached — determined by the size of the orifice left for the issuing air — at which the floating part of the bellows will remain nearly stationary. A bellows on this plan has been for some years attached to the engine that gives motion to the machinery in Truman and Hanbury's brewery, and its operation is spoken of by Mr. Davison, the engineer of those works, in the highest terms.

Another plan of governor was some years ago contrived by Mr. Hick of Bolton. Upon an upright spindle he wound a spiral feather, and then fitted upon the spindle a single ball, so that the ball might be moved up or down on the spindle, but would turn on its axis in the operation. To the ball were fixed two vanes, which, impinging upon the air when the ball was put into revolution with a high velocity, caused the ball to mount up on the spiral feather or thread. So long as the speed of the shaft upon which the ball was placed remained moderate, the ball continued at the foot of the spiral; but when the speed was increased, the impact of the vanes upon the air so far resisted the rotation, that the ball rose on the spiral feather in opposition to the force of gravity; and in its ascent it closed the valve. A governor upon this plan seems to be well adapted for steam vessels, if a spring be substituted for the ball. The ordinary governor, however, may be rendered applicable to the marine engine if the balls be made to move out horizontally instead of in an arc of a circle. It is clear that a common governor would not act at sea without this modification, as the balls would diverge or collapse at every heave of the ship. In Siemen's chronometric governor a clock movement furnished with a weight and pendulum is employed. The clock movement carries round a bevel wheel at a uniform speed, and another bevel wheel of the same size, and situated upon the same axis, is carried round by the engine in an opposite direction. A bevel pinion at the end of a crank arm gears with both wheels in the manner of a differential motion, and to this crank is attached a rod communicating with the throttle-valve. When both wheels are moving at the same speed the pinion remains stationary, but if one wheel travels faster than the other, the crank will be carried round upon its axis, and will thereby affect the throttle-valve. There appears to be too much complication in this contrivance to enable it to gain an introduction into practice, unless a clock movement be required for other uses than that of the engine.

The governor, as at present applied to regulate the steam-engine, acts only on the throttle-valve, to restrain the flow of steam into the cylinder; but in our humble judgment it ought also to act upon the injection-valve, to restrain the flow of water into the condenser. In all cases of large fluctuations of velocity, inconvenience and danger is the inevitable effect of the injection water being left without due regulation, and in steam-vessels in particular, accidents are frequently traceable to this cause. If the injection cock be adjusted to give admission to the right quantity of water when the engine is working with a mean velocity, it will clearly admit too much when the velocity is arrested so as to be brought to one half or one fourth of the common speed; and as the air-pump cannot, when it is working so slow, deliver the water which rushes into the condenser in undiminished quantity, the engine becomes choked with water, and the water sometimes runs back into the cylinder, and occasions fracture by resisting the descent of the piston. The most common cause of breakages in steam machinery is the entrance of water into the cylinder. Sometimes it passes over with the steam, when priming in the boiler takes place; and at other times it finds its way from the condenser, and this will more frequently happen if the cylinder exhausts from below than if it exhausts from the top or superior portion of the valve casing. The right remedy for this danger is to apportion the quantity of water admitted to an engine to the quantity of steam; and this may be accomplished by placing a throttle-valve in the injection pipe, which will also be operated on by the governor. But little condensing water will then be admitted when there is but little steam to be condensed, and the engine will neither be burdened by needless water nor starved into inefficiency by an inadequate supply. This innovation, with others of a similar character, were introduced into the Don Juan steamer ten years ago, but their intent at that time could hardly be apprehended. In steam-vessels propelled by the screw such resources are less necessary, as engines work with a much more uniform speed when applied to the screw than when applied to the paddle-wheel.

THE CATARACT.

The governors we have already mentioned are chiefly applicable to the rotative engine. The accredited governor of the single-acting or pumping engine, is the cataract, of which instrument there are many varieties. The cataract used by Smeaton and his predecessors, we have already described and delineated, in page 9.: the modern Cornish cataract is represented in plate 6. "Valve Gearing of a Cornish Pumping Engine," and is shewn in connection with the hand gearing, beneath which it stands. The same mechanism is again visible in plate 5., entitled "Cornish Pumping Engine," which is an elevation of a pumping engine of much efficacy, made at the Hayle foundry. In this last plate, the connection may be traced, of a dotted line, between the cataract shaft and the injection valve, situated at the end of a curved pipe, bolted on the condenser, and which communicates between the cold water cistern and the interior of the condenser. The cataract consists of a small pump plunger, and barrel, set in a cistern of water, the barrel being furnished on the one side with a valve, opening inwards, through which the water obtains admission to the pump chamber from the cistern; and on the other by a cock, through which, if the plunger be forced down, the water may be sent out again, with a rapidity proportionate to the size of the orifice left by the cock. The engine, in its upward stroke, which is accomplished by the preponderance of weight at the pump end of the beam, raises up the plunger of the cataract by means of a small rod, represented in the drawing of valve gearing already referred to — the water entering the pump-chamber through the spindle valve, which is also represented, and filling the pump-chamber completely. By the time the engine reaches the top of the stroke, it liberates the rod by which the plunger has been drawn up, and the plunger then descends by gravity, forcing out the water in the barrel, and at the same time opening the injection valve. If the cock of the cataract be shut, it is clear that the plunger cannot descend at all; and as, in that case, the injection valve cannot be opened, the engine stands still: but if the cock be slightly opened, the plunger will descend slowly, the injection valve will slowly open, and the engine will make a gradual stroke as it gains the water necessary for condensation. The degree to which the cock is opened, therefore, determines the speed at which the engine moves; so that by the use of the cataract, the speed of the engine may easily be adjusted to the quantity of water in the mine. There are other varieties of cataract employed besides that here described, but they all depend upon the same general principle. In some cases air is used instead of water, and in others a cylinder of oil is employed, fitted with a piston with a valve after the manner of a pump bucket, and a small side pipe, fitted with a cock, which communicates between the spaces on each side of the piston. When the piston of this cataract is forced down, the oil easily ascends through the valve into the superior part of the cylinder, but when it is drawn up, the oil can only escape by the curved pipe, from the space above the piston to the space beneath it, by passing through the contracted orifice of the cock; and, though a considerable counterbalance be applied, the piston, if the cock be partially closed, can only ascend but slowly. The effect is just the same as in the arrangement first described: the oil cylinder is perhaps to be preferred as being neater, when, from the nature of the foundations, or otherwise, the cataract has to be set among the valve gearing, but in other cases we should incline to the adoption of the other arrangement.

EXPEDIENTS FOR ASCERTAINING THE STATE AND POWER OF AN ENGINE.

Water Gauges. — There are three kinds of water gauges: the first the ordinary gauge cock, the second the glass gauge, and the third the float. The gauge cock, on being turned, shows whether it is water or steam that exists at the level at which it is inserted. There are usually three gauge cocks inserted in each boiler, at different levels; and the rule is to so feed the boiler that there will be steam in the top gauge cock, and water in the other two. The glass gauge consists of a glass tube set in front of the boiler, communicating in its superior portion with the steam space, and in its inferior portion with the water within the boiler, the position of the tube being so adjusted that the water level stands at about the middle of its length. The tube is connected at the top and bottom to the boiler by means of sockets furnished with cocks, so that the tube may be blown through by the steam to clear it, and the water and steam may be shut off if the glass breaks. It is unsafe to trust to the glass gauges altogether as a means of ascertaining the water level, as sometimes they become choked, and the water continues to stand high in the tube though it may have sunk low in the boiler. If the boiler be short of steam, however, and a partial vacuum be produced, the glass gauges become of essential service, as the gauge cocks will not operate in such a case, for though opened neither steam nor water will come out, but air will rush in. This sometimes occurs in practice, and glass gauges are then found to be of especial value. We may mention, however, that a vacuum in the boiler should never be suffered to occur, as if the boiler is short of steam the throttle-valve should be closed to a corresponding degree, or a higher degree of expansion should be employed, so that the due pressure of the steam may be maintained. A better economy is to be realised by this plan of procedure than by suffering the engine to draw from the boiler the attenuated steam. In steam-vessels the operation of blowing off cannot be performed, unless the pressure of the steam be considerably above that of the atmosphere, and the neglect of this operation entails evils which are of serious moment, and which are very expensive to cure.

The float-gauge consists of a float resting on the surface of the water, and communicating with an index, so that the fluctuations in the water level are, by reference to this index, made apparent. The float is usually of stone or cast-iron, but is so balanced by a counter weight as to make its operation the same as if it were a buoy of timber. In land boilers a float is generally employed to regulate the admission of the feed-water, and the same float may also indicate the height of the water within the boiler. The feed-water is admitted from a small open cistern at the top of the stand pipe, as shown in fig. 230. At the bottom of the cistern is a valve, which the float opens or closes, and into the cistern the water is poured by the feed-pump. When the valve is open the water runs down into the boiler, but when closed it runs away by an overflow shoot. The foot of the stand pipe penetrates to near the bottom of the boiler, so that steam cannot escape by it, but the water rises in the stand pipe to a height proportionate to the pressure of the steam, and a most effectual safety-valve is thus provided, which will come into operation in the event of a dangerous pressure being attained. In the stand pipe a float is placed, which rises and falls as the pressure of the steam varies, and opens or closes the damper leading from the boiler flue to the chimney. Some stand pipes are contracted in their diameter below the level at which the damper float usually operates, and danger has arisen from this cause; for the float has descended into this narrow neck when there was no longer a pressure of steam in the boiler, and by stopping up the passage it has prevented the access of the feed-water. The length of the damper-chain should be so regulated as to obviate accidents of this description, which are not unlikely to burst the boiler, by causing the boiler bottom or flues to become red hot.

Salt Gauges. — In steam vessels it is a commendable practice to apply salt gauges to the boiler, so that the water may never be suffered to reach an injurious degree of saturation. These gauges usually consist of glass balls, which operate on the principle of the hydrometer, rising to the surface when the water becomes highly concentrated, and therefore heavier. In some instances bulbs of this description, enclosed in a large glass tube, are fitted to the front of each boiler, but the general plan is to draw off some of the water into a separate vessel, and then to test its saltness by an instrument provided for the purpose. The Don Juan steamer was fitted with large copper balls, to determine the saltness of the water in the boiler: they were of course totally immerged in the water, and as the water increased in density they rose and opened the blow-off valve, which was made of such a construction as to be capable of being easily opened. There is too much refinement probably in this expedient, and the ball requires to be large to realise a sufficient motive force to make the action of the instrument certain, yet the operation of the plan is very complete, especially if conjoined with a self-acting feed, as was the case in the instance referred to. A good salt gauge is still a desideratum, for the plan of drawing off water from the boiler, and testing it by a hydrometer is very inconvenient in practice. A salt gauge, to be a convenient instrument, should indicate, by a hand or other simple appendage, the density at the time of observation of the water in the boiler, and such an instrument becomes of especial importance if the amount of water blown off be regulated by the position of the feed-cocks, as is done in the case of Mr. Lamb's blow-off apparatus for steam-vessels, which is now gaining an extensive introduction. In this apparatus the mouth of the blow-off pipe within the boiler is situated near the water level, whereby it catches and removes from the boiler the particles of impalpable matter which, by their subsidence on the flues, occasion scale. The collecting mouth, therefore, answers much the same purpose as the collecting vessel referred to in page 69., and the impalpable particles arising from the decomposition of the salt are carried away with the supersalted water. Mr. Lamb attaches a valve to the mouth of the blow-off pipe regulated by a float, with the view of preventing the steam from blowing off when the water has subsided below the said mouth, which is situated about 12 inches beneath the average water line. The float is made of copper, of the form of an oblate spheroid, with a tube passing through it for the reception of a spindle, the position of which in reference to the float is regulated by nuts above and below the float, which connect with screw threads cut upon the spindle. The valve resembles a flute key. The lower end of the spindle is attached to the valve arm, so as to enable the float to exert a greater power, and the upper end of the spindle moves in a guide attached to any convenient part of the boiler. By this apparatus the operation of blowing off is continuously performed, but when the salt gauge shows that the quantity of water blown off is either needlessly great or insufficient, the position of the feed-cock is altered so as to give a diminished or increased supply. When more feed-water is admitted, the float upon the surface of the water opens the blow-off valve more widely, and permits a larger quantity of water to be blown out; and when less feed-water is admitted, the contrary effect is produced. The operation of the float, therefore, is to maintain the water at a uniform level, and also to preserve the water within the boiler at a uniform density so soon as the right position of the feed cock is ascertained. In boilers which are thus worked, or to which brine pumps, or any continuous blow-off contrivances are applied, an efficient salt guage is indispensable. as there can otherwise be no intimation of the accidental interruption of the operation, and much mischief may be the result. In the ordinary way of blowing off, where the engineer keeps the blow-off cocks open until the water level has descended any given number of inches, it is certain that, if the water level descends, a certain volume of super-salted water has been ejected; unless, indeed, as has sometimes happened where there is a difference of pressure in the different boilers, one boiler has discharged its contents into the other when all the blow-off cocks are opened at once. But in the ordinary operation of blowing off one boiler at a time, a determinable quantity of water is expelled by blowing out at determinate intervals with a certainty which leaves nothing to the chances of accidental derangement, and which the use of the salt gauge in the case of boilers fitted with any description of continuous blow-off is indispensable to insure.

Steam Gauge. — The steam gauge consists generally of a simple tube, sometimes of glass and sometimes of iron, bent so as to form the letter U. One of the ends is placed in communication with the boiler, and the other end is open to the atmosphere. Into the bent part of the tube mercury is poured, which, if not acted on by the steam, will stand at equal heights in both legs of the tube. If, however, the steam be admitted to act upon the mercury at one of the extremities of the tube, it will force it up in the other leg, and may be made to indicate the amount of pressure on a divided scale. The scale is commonly divided into inches and parts of an inch, each inch corresponding to a pressure of very nearly one pound on the square inch. Some people prefer estimating the elasticity of the steam by pounds per circular inch. For this purpose each of the divisions of the scale ought to be $1\frac{3}{10}$ inches, and these divided again into 10 equal parts, when the pressure in lbs. and tenths of a lb. will be shown by the scale. When the tube is constructed of iron, it is necessary that a float of wood resting on the top of the mercury should ascend above the tube, and indicate on a proper scale the place of the mercury. It is clear that every inch the mercury rises in the open end of the tube occasions a difference of level of two inches, for the level in the leg pressed on by the steam falls an inch at the same time that the level in the open end rises an inch. Some steam gauges consist of a straight glass tube, with one end terminating in a small cistern of mercury, while the other end is open, and the mercury is forced up into the tube by the pressure of the steam. In this case the graduation has to be such that a pound pressure will be represented by two inches in height upon the scale, for the level of mercury in the cistern does not subside appreciably by the rise of mercury in the tube. The syphon gauge is the one generally employed, and it appears to be entitled to the preference it enjoys. Every boiler ought to be provided with a steam guage as a precaution of safety, as well as a means of seeing that the steam is kept steadily up. If the pressure rises to any dangerous pitch, the mercury will be blown out of the guage, and the escape of steam will notify the existence of danger. In such case, if the safety valve cannot be raised, from derangement or otherwise, the best plan is to open the blow-through valve of the engine. To start the engine might cause a flow of water from the feed-pump over hot plates within the boiler, if the water be at the same time low within it, and an explosion might be the consequence of such an indiscretion.

Vacuum Gauge.—The vacuum gauge is a barometer for determining the relative elasticities of the air and of the attenuated vapour in the condenser. It consists of a glass tube, of which the inferior orifice is inserted in a small cistern of mercury, while the superior orifice is fitted with a small pipe, which communicates with the interior of the condenser. The air presses on the surface of the mercury in the cistern, while the pressure of the condenser vapour only exists within the tube, and the mercury rises in the tube to a height corresponding to the difference of these pressures—usually to a height of about 27 inches. There is a good deal of oscillation in the mercury of a vacuum gauge if the cock in the pipe leading from the top of the tube to the condenser be opened fully, and it should therefore be nearly closed before the observation of the quality of the vacuum is made, else it will be very difficult to tell at what point the mercury stands on the average, in consequence of its rapid rising and subsidence. In the graduation of vacuum gauges reference enough is not generally had to the size of the mercury cistern, which is usually made small; and as the subsidence of the level of the mercury in the cistern falls considerably when the tube becomes full, the graduation, if made in inches, is correspondingly inaccurate, as the divisions should be less than an inch apart to represent inches, if the surface of the mercury in the cistern falls. Some vacuum gauges are made on the principle of indicating the difference between the vacuum in the condenser and a perfect vacuum, instead of the difference between the vacuum in the condenser and the pressure of the atmosphere. This species of vacuum guage is much used in sugar refining, and is convenient there from its portable nature; but it has not met with any extended adoption for the uses of the steam engine. A syphon vacuum gauge, like the steam gauge in form, is also sometimes used; but the straight glass tube, arranged in the manner we have described, is generally preferred to any other arrangement.

The Indicator. — The indicator is an instrument for determining the amount of power actually exerted by an engine. In computing the power of engines, one important element is the unbalanced pressure of the steam on the piston; and any inaccuracy in the statement of this particular must vitiate the calculation, and give an erroneous result. In all ordinary cases, even when no expansion gear is used, it is wrong to reckon the pressure of the steam in the cylinder as uniform, or the condensed vapour as of a constant elasticity; and to assume that the pressure in the cylinder is the same as that indicated by the steam gauge, is to introduce a fallacy into the computation of power. The use of the indicator is to measure and register the variations of pressure during a complete stroke of the engine, and thus to obtain accurate data whereby the effective power of the engine may be computed.

The indicator consists of a small cylinder *c*, plate 4. placed in connection with the cylinder of the engine either above or below the piston, and fitted with a piston, P, which is connected with the spiral spring, *s*. By opening the cock of the indicator the steam is admitted below the piston, P, on which it presses during the whole stroke. If the pressure were uniform, the piston would remain stationary; but if the pressure vary, the piston will have corresponding movements either up or down. If a pencil, *p*, be attached to the piston rod, it will register the variations of pressure upon a piece of paper held against it; but, unless some provision were made to give a clear space upon the paper at each instant of time, one mark of the pencil would be upon the other, and the registration could not be deciphered: but, if the paper receives a continuous lateral motion in one direction during the down-stroke of the piston, and a reversed motion during the return stroke, while the pencil moves vertically, a continuous line will be traced upon the paper, which will inclose a space, and the vertical ordinates of the figure will represent the effective pressure during a complete stroke. Instead, however, of using a plane surface, as was done in Boulton and Watt's establishment for some time after its formation, it is now the universal practice to wind the paper round a cylinder, or roller, which is made to turn upon its axis with a reciprocating motion, and the apparatus is thus rendered more compact. If the pressure of the steam were uniform, the line described upon the paper would be in a plane perpendicular to the axis of the roller, so that, if the paper were unrolled, the line would be straight. The paper is fastened to the roller by means of a catch, *h*, the edge of which is graduated. Before the instrument is connected with the steam cylinder, the roller is set in motion, and the pencil then describes a neutral line, which represents the pressure of the atmosphere—any vertical ordinate above this being the steam pressure above that point, and any vertical ordinate below, the pressure below it. If the connection between the indicator and the cylinder be now formed, while steam is entering the cylinder, the piston of the indicator will rise; and, if steam is escaping from the cylinder, it will fall; the extent of rise and fall being regulated by the spiral spring, which yields more as the pressure becomes greater. The vertical motion of the pencil, combined with the circular motion of the roller, will form a curve more or less regular, the vertical ordinates of which represent the values of the steam pressure and vacuum during a complete stroke, measured by the scale which is marked upon the roller clasp. The graduation of this scale depends upon the strength of the spring, *s*, which forces the piston down when the steam ceases to force it up; because, the stronger the spring is made, the smaller is the distance through which steam of a given force will compress it by raising the piston. The alternate motion of the roller is given by connecting it with any reciprocating part of the engine, such as the parallel motion, by means of a cord attached to the pulley, *a*, which is fixed upon the same axis as the paper roller, *d*. This cord gives motion in one direction, and the return motion is received from a spring, *m*, which is coiled up like a watch-spring; *l* is a guide pulley for changing the direction of the cord when it passes from the pulley, *a*; it is not shown in its place except in the bottom plan, where part of it is dotted in.

Let us now suppose the engine to be in motion, and the stop-cock of the indicator closed. If the cord be drawn out by hand, or connected with the engine, the pencil pressing against the paper will describe the horizontal line representing the atmospheric pressure; and if, when the piston is at the top of its stroke, the indicator stop-cock be opened, it will commence its registration. When the steam begins to rush into the cylinder, it will, of course, also press upon the piston of the indicator, which it will raise, and with it the pencil; and the roller, with the paper upon it, being moved by its connection with the engine, a line will be traced upon the paper, which rises higher up on the cylinder as the pressure of the steam increases, and comes lower upon it as the steam pressure subsides. The area of the curve traced out by the pencil, therefore, represents the pressure on the piston through all its variations, and, when multiplied by the number of strokes, represents the power exerted by the engine. This power has no connection with the *nominal* horse-power, which is determined by the dimensions of the engine, and which does not vary with variations in the pressure of the steam; but it is the *effective* power, or the power actually exerted.

The indicator, however, not merely tells the amount of power exerted by every stroke of an engine, but the nature of the faults by which the power is impaired. A particular form of the indicator diagram shows that the ports of the cylinder are too small; and the indication in such a case obviously is to enlarge them. If the valve be wrongly set, the indicator will explain the nature of the imperfection, and its adjustment then becomes easy. By the indicator too the amount of power consumed by each of the several mechanisms of a factory may be determined, and the relative values of different oils fixed that may be employed for the lubrication of the shafts. If, for example, it is wanted to know the amount of power consumed by a fan or a saw-mill that may be driven by the engine, the machine in question has only to be put in connection with the engine, while all the rest of the machinery of the factory is cast off; and if the indicator be applied to the engine, the amount of power consumed in driving the one machine will be determined; and then it will be found, by taking another diagram, with all the machinery on, what proportion this part bears to the total power. In testing the quality of oils, if it be found that the engine requires more power to drive the shafting with one kind of oil than with another, that which involves the largest expenditure of power is, of course, the worse. To read off the indications of the indicator is a thing every one may do after the foregoing explanation. The pencil describes a curved line inclosing a space. Across that space any number of lines may be drawn at right angles to the atmospheric line. The lengths of the lines are then measured on a scale, and their mean taken, which mean represents the power exerted, as more fully explained at page 246. The indicator is an invention of Watt's, but it does not very clearly appear who it was that first applied the pencil to trace a curve. The application was, however, first made at Soho, probably by Mr. Southern or Mr. Creighton.

Continuous Indicator. — A continuous indicator is an instrument that will not merely ascertain, but also register the work done by an engine during any given period, whereby the performance of one engine may be compared with the performance of another, to the end of ascertaining which is the most economical in fuel. In Cornwall this object is accomplished by means of a counter, which merely registers the number of strokes made by the engine; but this expedient will only answer where the load upon the engine is constant and easily measureable, and becomes of but little avail in a steam vessel, where the load is continually varying. The invention of an instrument of a simple kind, that will record the varying power of the engine under all circumstances of speed and variation of expansion, becomes an object of no trivial importance, when it is recollected that such an instrument is indispensable to the success of any effectual scheme of registration. By registration we mean the determination by an authorised person of the power exerted by steam vessels, or, in other words, the *work done* in relation to the *fuel consumed*, and the publication of these results obtained from a large number of steam vessels at regular intervals; so that it may appear on the face of a table suitably drawn up what steam vessels are the most effectual. These published tables would, therefore, be identical in all their main features with the tables published in Cornwall by the Messrs. Lean; and indeed the measure we propose consists in the extension to steam vessels of the system of registering the *duty* of engines pursued in Cornwall, and which has produced such beneficial effects in that district.

The best proof of the saving in fuel derivable from the plan of registering the duty of steam engines consists in an enumeration of the wonders it has already done; and we find that the amount of work performed in Cornwall by a bushel of coal, represented by 20,000,000 in 1815, had arisen to 60,000,000 in 1843. Nor is this a solitary case, but, on the contrary, it is the *average* duty of all the engines registered at the two periods, so that the expense of fuel to do the same amount of work is at present only one-third of what it was in 1815, and we think we may add only one-third of what it would have been now, had the plan of registration not been adopted. The Messrs. Lean have drawn up a table which makes the value of this system very conspicuous, and from which it appears that the Cornish mine owners are now saving about 85,000*l.* per annum in their limited operations, by the simple expedient of registering and publishing the duty of their engines. Such a practice puts all the engineers upon their mettle, and induces an emulation out of which improvement cannot but spring; and at the same time it stimulates all engine attendants to a more sedulous attention, as any negligence on their part will be sure to tell to their disadvantage. If such a saving can be realised out of the contracted sphere of Cornish engineering, what a magnificent result might not be realised by the application of the plan to the innumerable steam vessels of this country! Yet the saving in the cost of the coal in the case of steam navigation, important as it would be, is not the greatest benefit of such an economy: the powers of steam navigation would be prodigiously increased, and its profits correspondingly augmented, by any improvement by which the quantity of coal carried was materially lessened; for steam vessels could then go farther without a relay of coal, or could carry more cargo, and the growth of our steam marine would just be in proportion to the extension of the limits which now hinder its development.

It is needless, however, to dwell much on the advantages of the system of registration, as they must be conspicuous enough to every one who gives attention to the subject. Professor Moseley professes to have invented an indicator of the continuous kind, but it is far too complicated for ordinary practice; and as some of the parts drive the other parts by friction surfaces which are apt to slip should a little oil chance to fall upon them, its indications are correspondingly uncertain. A suitable indicator being obtained, every steamer of any pretensions should be provided with one, and an inspector should then be appointed, in whose skill and honesty all parties have confidence, and whose business it should be to examine the indications of the several instruments, and make up from thence tables of the performance of each vessel, which should periodically be published. The quantity of coal consumed could of course only be got at by a reference to the coal accounts of the several vessels; and it would be a good thing if those coal accounts were all kept upon a uniform plan to facilitate the discovery of this element.

A continuous indicator of a very complete description was some years ago brought under the notice of the British Association by Dr. Lardner, though its expense and complication were too great to warrant its introduction in practice. A web of paper was wound upon a small brass drum, and a larger drum, which was put into revolution by means of clock-work, wound the web of paper off the small drum on to itself. At suitable distances round the larger drum pencils of different colours were placed, which were acted upon by floats placed in syphon tubes of mercury, to which the steam-pipe, condenser, &c. were respectively connected. When the pressure of steam in the boiler varied, the pencil attached to the float in the syphon guage communicating with the boiler was elevated or depressed correspondingly, and traced a line upon the drum above or below the right position. At the termination of the voyage the paper was taken off and translated into words, and the difference in the colours of the different pencils prevented the lines made by each from being confounded with any other. There was more trouble connected with the use of this instrument than engineers would willingly take, and more expense than the proprietors of steam vessels would willingly incur, added to which it took no satisfactory cognizance of any variation in the degrees of expansion, though that is the most important of the elements demanding registration.

Counter.—The counter is an instrument with wheelwork so contrived, that, by every stroke of the engine, an index hand is moved a certain distance forward, so that it registers or counts the number of strokes made by the engine during any given period. The construction of the counter varies very much: in most cases, however, the wheels are moved round by a pendulum attached to some vibrating part of the engine, the wheel being carried on one tooth by every vibration. Some of the French counters are extremely neat and portable, being much like a pedometer watch in size and appearance. A very elegant counter for locomotive engines has been contrived by Mr. Adie: an endless screw works into the rim of two small wheels, situated on the same axis, but one wheel having a tooth more than the other. A differential motion is thus obtained, of great slowness, for the wheel with the additional tooth will only move slightly more slowly than the other wheel, and the result is indicated by the difference of the two speeds. The end of the screw is attached to a revolving part of the engine, by means of an appropriate fastening, and the wheels hang down like a pendulum from it, and do not turn with the revolving part in question, so that the wheels are turned on their axis by the screw, without anything of the nature of reciprocation. The counter was first introduced by Mr. Watt, and was attached by him to the Cornish engines for the purpose of showing the proportion of savings in fuel due to him from the application of his improved engine, and in the case of those engines which were uniformly loaded the counter afforded a correct indication of the power exerted. The number of strokes of the engine multiplied by the capacity of the pump, and the height through which the water is raised, will give a quantity representative of the engine power, and in the case of pumping engines, the indications of the counter will enable us to determine the *duty*, the registration of which has in Cornwall been productive of such beneficial effects.

Dynamometer.—In screw vessels the forward thrust of the screw has been measured by a dynamometer, an instrument constructed on the principle of a weighing-machine, in which a small weight, or spring pressure at the index will sustain a much greater weight or pressure at the other end. In the Rattler screw steamer the forward thrust of the screw, as determined by the dynamometer, was found to be about four tons, and it was also found that when a piece of paper was drawn slowly along beneath the index, a pencil attached to the index described upon the paper a serrated line showing great fluctuations of pressure in the different positions of the screw. The *greatest* thrust is when the screw blade is in a line with the stern post. A dynamometer has also been employed in Woolwich dockyard to test the tractive force of paddle-wheel steamers. Morin's dynamometer is usually employed for ascertaining the resistance of railway trains. It consists substantially of two blades of steel, the flexure of which indicates the resistance.

CHAPTER IX.

VARIETIES OF THE STEAM ENGINE.

CONDENSING AND HIGH-PRESSURE ENGINES.

We have already intimated that steam engines of every kind are divisible into two great classes—high-pressure engines and condensing engines. Condensing engines are sometimes also worked with a high pressure of steam, and the distinctive appellation of high-pressure engines applied to engines of which the steam is not condensed, is open to exception; but we shall take the name as it stands, as our ambition does not rise to the coinage of a new nomenclature. All locomotive engines are of the high-pressure variety; and generally all engines are made on the high-pressure plan, where the carriage of condensing water would be inconvenient, or the first cost of the machine becomes a point of more importance than an increased consumption of fuel. High-pressure engines are, *ceteris paribus*, necessarily more expensive in fuel than low-pressure engines, as they occasion the loss of the power derivable from a vacuum; and as the quantity of heat in the *same weight* of steam is nearly the same at all pressures, there is no countervailing source of economy to compensate for this deduction. The use of high-pressure engines in circumstances in which the low-pressure engine is applicable, is not to be commended; and the high-pressure engine is rarely employed for other purposes than locomotion on railways, except in the case of very small engines required for some temporary or trivial purpose. Considerable numbers of small high-pressure engines are sent to the West Indies, for driving sugar machinery, but even in that case, though their greater facility of conveyance is a consideration, their use can hardly be defended. Where high-pressure steam is employed, it is expedient to make the pressure considerable, as the deduction to be made for the pressure of the atmosphere is less in proportion, with a high, than with a moderate pressure. Some locomotive engines are worked as high as 90lbs. on the square inch. It must be needless to explain after our previous expositions, that in the high-pressure engine the steam, after having given motion to the piston, is suffered to escape into the atmosphere, whereas, in the low-pressure engine, the steam, after it has impelled the piston to the end of the stroke, passes from the cylinder into the condenser, where it is condensed by a shower of cold water, its condensation occasioning a vacuum or void, which sucks down the piston, and adds correspondingly to the force of the moving power.

THE PUMPING ENGINE.

We have in page 13, described generally the pumping engine, as arranged by Watt at an early period of his career, and the modern pumping engine differs from this primitive type only in a few details of secondary importance; excepting, however, the use of steam of a higher pressure, and the larger employment of the principle of expansion, by which a greatly increased economy of fuel has been realised. The engine entitled "Cornish Pumping Engine, Hayle Foundry," plate 5, is a good specimen of the pumping engine, as now constructed, and represents an engine of noted economy in fuel. The valve gearing of the same engine is shown in plate 6, entitled "Valve Gearing of a Cornish Pumping Engine, Hayle Foundry." This valve gearing operates in the same manner as the valve gearing of Watt's engine, figured and described in page 11. fig. 10; but the valves, instead of being of the ordinary spindle kind, are of the equilibrium description, so that they may be raised by a trifling force. The equilibrium valve consists, substantially, of a cylinder, open at both ends, and capable of being moved on a fixed piston with an upright stem. The cylinder stands over the hole in the steam box, and the piston prevents the steam from passing through it; but when the edge of the cylinder is raised from the bottom of the box, the steam then gains an exit, and it is clear that the cylinder can be raised without any considerable exertion of force, as it is pressed equally in all directions. Instead of the rubbing surface of a piston, however, two ground valve faces are employed in practice, and the moving part of the valve is not a perfect cylinder, as will be obvious by referring to the right-hand figure of the plate of valve gearing. The spindle valve in this arrangement, standing to the extreme right, is merely a stop or throttle valve, for regulating the flow of the steam. Of the other two valves shown in that figure, the smaller is the steam valve, and the larger the equilibrium valve: the first for admitting the steam to the cylinder, for accomplishing the down-stroke of the piston, and the second for enabling the steam above the piston, at the termination of the stroke, to pass during the return stroke to the space beneath the piston. The eduction valve is seen in the sectioned figure on the extreme left of the plate: its function is to let the steam escape to the condenser when a downward stroke is to be made. The eduction valve is generally opened a short time before the steam valve, so that the steam may have a longer time to be condensed, and that the downward stroke may be accomplished immediately that the steam is admitted. The valves are, always, moved by tappets on the plug rod, as in Mr. Watt's arrangement, but the details are slightly different, and differ in different engines. The details of the specimens we have selected are as good as any that have come under our observation: the condensers, we are inclined to think, are often made too small by the Cornish engineers.

All the Cornish engines are furnished with a steam jacket to the cylinder, and, in some cases, a flue winds spirally round the jacket, carrying hot air from a small fire in the engine house, to maintain the temperature of the steam unimpaired. Where this is not done, the cylinder is encased in a large jacket, filled with some non-conducting substance, or is covered with wood. In plate 7, entitled "Pumping Engine at Vauxhall, by R. Hosking, Engineer," a very effectual casing of this kind is shown; and the covering is extended to the steam pipes and boilers, which are carefully enclosed in the Cornish practice. It is by this effectual prevention of the needless dispersion of the heat, and by the large use of the principle of expansion, that the economy of the Cornish engine is realised, for the boiler has but slender claims to excellence, and is in every respect inferior to the marine boiler, whether flue or tubular. A material economy is certainly derivable from the use of the steam jacket, though on what principle such an economy should result, is not easily discoverable. The jacket presents a larger cooling surface than the cylinder itself, so that its use might reasonably be supposed to occasion an increased loss from condensation; nevertheless, of two engines, in every respect identical, but one provided with a steam jacket, and the other without it, the engine without the jacket has given a considerably inferior result; and the same engine, if worked with a jacket, has proved itself more efficient and economical than if worked without it. We have given in pages 55 and 70, views of Cornish boilers of the most approved kind. The boilers are easily made, but the ashpits are much too contracted, and the water level is of insufficient area, so that boilers of this kind are difficult to keep, and are liable to prime. The steam pipe of the Cornish engine is greatly smaller than is usual in other engines, and no inconvenience arises from its contraction, while the loss of heat from radiation is diminished. Many of the Cornish engines have a steam casing in the top and bottom of the cylinder, as well as around it; and in some also a space is left for steam in the stuffing box, so that if any leakage takes place it will be a leakage of steam, which will only increase the consumption of fuel, instead of a leakage of air, which will diminish the power of the engine. To accomplish this object, the stuffing box is made very deep, and above the packing a lantern brass is introduced, on the top of which packing is again laid, and the whole is pressed down by the gland. The lantern brass leaves a space between the two packings, into which steam is introduced by a pipe from the steam pipe.

In most pumping engines one end of the beam is made longer than the other, the intention being to enable the cylinder to have a long stroke, without communicating such a velocity to the pump buckets as will make them strike hard, and wear themselves quickly out. One advantage of a long stroke is, that high pressure steam may be used without being obliged to make the parts inconveniently strong; for the principal parts of the engine have to be made of the same strength whatever be the length of the stroke, and to increase the diameter of the cylinder, to compensate for shortness of the stroke, involves the necessity of a strong and expensive engine. Woolf's plan of employing two cylinders is sometimes used as an alternative remedy, and in some recent engines the plan has been much simplified, by placing the small cylinder on the top of the large one, and working both with the same piston rod; but, as we have explained in page 13, there is no theoretical gain by the use of two cylinders; and although there is less irregularity in the impelling force, there is greater complexity in the machine, so that a long stroke with an unequal beam appears to be a preferable expedient. We have already, in page 121., and the following pages, shown that there is no loss of power occasioned by the use of the crank in steam-engines, and we have here to combat the corresponding supposition of a corresponding loss in pumping-engines, from the inertia of the matter put in motion at each reciprocation. The first error, that of a loss of power by the crank, we have already disposed of, on the principle of virtual velocities, in connexion with the consideration, that as no power can be created by a mere combination of levers, so none can be destroyed thereby. The second, and more respectable fallacy, that power is absorbed in incessantly producing and destroying the motion of the reciprocating parts of a machine, we shall consider at some length, — regard being had, in our remarks, rather to the " number, character, and qualifications " of the holders of the obnoxious doctrines, than to the intrinsic importance of the heresy itself.

First of all, then, it is obvious that it takes some power to put a beam in motion, supposing it balanced upon its centre; and when motion has been communicated to it, an equal amount of force, applied in the opposite direction, is required to destroy the motion. To one contemplating the heavy masses of matter to which motion is alternately imparted and opposed, the inference is natural, that a proportion of what would be otherwise available power is inoperatively expended, first in overcoming inertia, and, second, in destroying momentum. The working-beams and side-levers of steam-engines afford the most familiar example of this. We there see a weight of several tons, including the various attachments, moving with considerable velocity, alternately in opposite directions. Some other machines, we shall find, supply more striking illustrations, such as planing machines, stone-cutting machines, reciprocating saw-mills, &c. In fact, instances of incessant reciprocation are not much less common than instances of continuous rotation. Unlike the loss from friction, atmospheric resistance, viscidity, and imperfect elasticity, we shall find that this loss, if any exists, is of a nature susceptible of mathematical investigation. We shall take the *reductio ad absurdum* plan, and show that if the ultimate loss be any thing, it must in some instances be so great as to absorb the whole power of the machine. In the case of an ordinary engine-beam, with the usual connexions of piston, connecting-rod, or plunger-pole, &c., the inertia of the beam, or its resistance to motion, may be regarded as equivalent to that presented by a certain weight at each extremity. It is a familiar problem in theoretical mechanics to determine at what distance from the axis the matter of a beam must be concentrated, in order to oppose the same resistance to motion that the beam does in its natural state. This distance is called the radius of gyration, and the point the centre of gyration. Assuming, again, any distance — such, for instance, as half the length of the beam — we can determine conversely what proportion of the mass placed at that distance will present an equivalent resistance: this may be termed the mass of equivalent inertia for that radius.

Suppose the beam in question to be a prism, of which the length bears a great proportion to the other dimensions; then, if we imagine one third of the weight to be placed at each extremity, and the rest to be annihilated, the resistance to angular motion would continue the same, and one third would represent the mass of equivalent inertia. In a common beam we may take one fourth as the mass of equivalent inertia at the extremity of the lever: to this must be added the gross weight of the attachments to the outer ends, and that of the connexions to the intermediate parts, reduced, in the proportion of the square of their actual distance from the main centre, to the square of the half length of the beam.

Take, then, the case of a winding engine at an inclined plane on one of the coal railways in Lancashire — cylinder, 18 in. diameter; length of stroke, 6 ft.; heavy beam, which may weigh from 2 to 3 tons, one fourth of which call 13 cwt.; weight of the other reciprocating parts, say 27 cwt.; total, 40 cwt. We may then consider the engine-beam as a simple weigh-beam without weight, but having suspended at each end a scale-pan containing 20 cwt. This engine sometimes makes forty strokes per minute, giving a velocity of 480 ft. per minute, or 8 ft. in the second; in the fourth part of a stroke, or three-eighths of a second, this weight has had a velocity of 12 ft. per second communicated to it, the maximum being to the average velocity as the semi-circumference to the diameter; so that a force had been in operation which, acting for one second, would produce a velocity of 32 ft. per second.

To put 2 tons in motion, at a velocity of 12 ft. per second, requires a mechanical power equal to the descent of that weight through the space it would fall freely, to acquire that velocity — that is, through 2 ft. 5 in.: thus, during each half revolution, or single stroke of the engine, we have a force expended equal to 2 tons, or 4480 lbs., moving 4 ft. 10 in.; but the piston having an area of 254 square inches, it will be found that a pressure of 14 lbs. per inch is absorbed in moving and checking the reciprocating parts. The ordinary pressure in the boiler may be from 25 to 30 lbs.; but the actual pressure on the piston cannot, at that speed, exceed 15 or 18 lbs.; and thus we should have three fourths or seven eighths of the whole power spent in moving the working parts. In spite, however, of this great deduction, the engine is found to perform its work with ease; which could not be the case if the loss were a real one. In fact, on the above computation, supposing the velocity to be somewhat increased, it would take more than the whole pressure of the steam merely to keep the engine going. So far, however, from this being the case, it is found that when the pressure on the piston is constant, the useful effect is in the direct proportion of the velocity.

Let us now take a different example. Suppose the case of a pumping-engine with 72-inch cylinder, and 10 ft. stroke, weight of plunger-pole, 30 tons, with balance-weight at other end of beam; weight of reciprocating parts referred to the end of the beam 7 tons, total reciprocating weight in lbs. 150,000. Suppose the number of strokes to be ten per minute, and a pause of half a second to be made after each single stroke, the average speed of the piston would be 240 feet per minute; and conceiving the acceleration and retardation to take place uniformly, the greatest velocity will be 480 feet per minute, or 8 feet per second, which is the velocity a body falling freely through the space of one foot would attain. Now, taking the power spent in retardation as equal to that spent in acceleration, we have for each double stroke of the engine a weight of 150,000 lbs. moving 4 feet (equal to 600,000 lbs. through 1 foot), which, reduced in the proportion of 4 : 20, gives 30,000 lbs. as the constant pressure upon the piston, = 7½ lbs. per square inch, supposing both strokes to be effective, but = 15 lbs. supposing only one, — an amount which in most cases would be more than sufficient to absorb the whole power of the engine. In this computation, we have proceeded on the authorised plan of adding the force required to put a body in motion to that required to destroy the motion, and presented the two as the sum of the power expended; but the truth is, that these two forces, being exerted in opposite directions, not their sum, but their difference, should be taken, and these being for the most part equal, they neutralise each other, and the actual power absorbed is just nothing at all. In the case of the water in the pumps the same remark is applicable, for though power is consumed in putting it into motion, this power is again given out in maintaining the flow after the stroke has terminated. In the Cornish engines this action is particularly visible, and the water will be found to continue to flow from the pump for some time after the completion of each stroke.

The pump-valves of engines working high lifts are a continual source of trouble and expense, and many expedients have been contrived to abate the shock and tremor caused by their rapid closing. Of these, the best is probably the valve known as Harvey and West's, which is, in all its material features, identical with the balance-valve, represented in plate 6 entitled "Valve gearing of a Cornish engine." This valve presses down with very little force, and an annular recess is frequently made in the pump bucket, which is filled with end wood, on which the valve falls. A good plan would be to make in the valve a recess, to be filled with water, which must be forced out by a corresponding protuberance on the bucket before the valve can close, and the necessity of forcing out the water will cause the valve to close gradually, and thus take away the shock. In some of the French and American engines, canvass valves are used even for the air-pump; and the plan has been recently introduced into English engines, which are intended to work at a high speed — in some cases with good effect; though in others, probably from the employment of an inferior quality of canvass, the valves have worn out very quickly. The bucket consists of a metal disc, perforated with a large number of small holes, and these holes are all closed by a canvass disc, which rises and falls like a common pot-lid valve; with the exception that it is bound down at the eye, and the edges only left. Indian rubber has been tried as well as canvass, but it sinks too much into the holes, and has not answered so well. Plies of canvass, stuck together by Indian rubber, would probably be the best material.

If there be any case in which the use of an engine-beam can be excused, it is in the case of a pumping-engine. Direct action is inconvenient and precarious over the mouth of a mine, and we do not conceive that the beam of the pumping-engine is likely to be so soon discarded as in other cases. The main-beam rests on a wall of masonry near the mouth of the mine, as may be seen by a reference to the plate of a " Cornish pumping-engine." At the one end of the beam is the cylinder, and at the other end the pump-rod, which penetrates into the mine. From the pump-rod end of the beam the rods for working the air-pump and feed-pump are suspended. The air-pump is shown in dotted lines, and beyond it appears the condenser, situated in the cold water cistern, with a valve attached to the end of a curved pipe, for admitting the injection water —the valve being wrought by the cataract which stands beneath the valve gearing. A rod passes through the end wall of the house, for adjusting the position of the centre of the radius-bar of the parallel motion. The cylinder end of the beam is armed with catch-pins, which strike on the spring beams stretching from the lever-wall to the end of the house, if the piston proceeds down so far as to endanger the cylinder bottom. The feed-pump stands on the top of the eduction pipe: the valve gearing we have already explained. It is usual in the Cornish practice to make the lowest pump of the series of lifts, a lifting pump, and all the others forcing pumps. The plungers of the forcing pumps are more easily packed than the buckets of the lifting pumps; and there is not the same risk of drawing air, but the lowest pump is made a lifting one, to facilitate extensions to a lower level, and also to prevent the pump valves from becoming inaccessible if the water accumulates in the mine.

The pumping-engine erected at Vauxhall by Mr. Hosking is a very creditable specimen of this variety of engine, and may be safely taken by others as a model. There are parallel motions it will be observed, and catch-pins at both ends of the beam. Winches are placed above the cylinder, and pumps to raise the piston, and pump buckets easily. There is a prejudice among the Cornish engineers to metallic packing in the pistons, and the use of hemp is attended with much trouble, from the continual screwing down and renewal it requires, especially if the pressure of the steam be considerable; but this prejudice is now wearing away, and metallic packing is gaining a gradual introduction. Notwithstanding all the ingenuity, however, expended upon the Cornish engine, and the very efficient performance to which it has attained, it appears to us to stand on the verge of early supercession, and we question whether it can maintain its ground for many years. The centrifugal pump is now under trial as a pump for the drainage of mines, and should the results which have been realized be confirmed by more extended experience, there cannot be a doubt that the whole of our present system of raising water must undergo a revolution. Small engines working at a high speed will then perform the functions of the cumbrous and lethargic pumping engine; smaller pipes will suffice, as the flow of water through them will be continuous, and pump valves, with which there is much trouble at present, will cease to be necessary. The present Cornish engines, though rudely made, are very expensive, as there is an immense quantity of iron in them; besides which, the engine-house and foundations require to be so strong and massive, that they add largely to the cost.

THE ROTATIVE ENGINE.

Of the rotative land-engine, the sixteen-horse power engine of Messrs. Maudslay & Field, represented in plate 8, may be taken as a good example. It is our conviction, however, that this species of engine must go altogether out of use, as several kinds of direct-action engine are far more simple and compact, and appear to be in every way entitled to a preference. One of these is the oscillating engine; another is the species of engine attached to Robinson's cane-mill, represented in plate 9, and there are several other varieties. We shall not, therefore, here dwell upon any description of the ordinary rotative or mill-engine, as we look upon it now as a mere piece of antiquity, and although as a necessary part of our plan, we give in pages 206—214, a full account of the details of the ordinary beam rotative engine in its most approved form, we have not a word to say in commendation of that species of engine. The jacket in Messrs. Maudslay's engine, plate 8, it will be observed, is cast in the same piece with the cylinder. The valve casing is provided with packing ports on the back, upon the lowermost of which the blow-through valve seat is cast. The condenser is situated in the cold water cistern, beneath the cylinder. Mr. Fairbairn's 60-horse power engine, plates 10 and 11, has the peculiarity of a toothed fly-wheel: in the rest of the arrangements there is little unusual. In some cases the double-cylinder engine is used for driving mill-work, and some very excellent specimens of this variety of engine have been produced by Messrs. Rennie, Messrs. Hall of Dartford, and Mr. Hick of Bolton. In engines for driving cotton-mills, the double cylinder plan may perhaps be an expedient one, for then the equability of motion is of the highest importance; but in ordinary cases, where expansion is desired, it appears to be the preferable way to use either two smaller engines, set at right angles on the shaft, or a single cylinder, with a heavier and swifter fly-wheel. There cannot be a doubt, moreover, that engines working at twice the usual speed, after the manner we have already recommended, must come into use for driving cotton mills; and if the speed be greater, the expansion may be carried further, without impairing the regularity of motion. The details of this species of engine we need not here enter upon, as the necessary information respecting them will be found in pages 206 to 215.

MARINE ENGINE.

The marine engine has now become the most important variety of the steam engine, not merely on account of the great extension of steam navigation, but because it is fast superseding the ordinary steam engine, even for land purposes. We shall therefore enter into the consideration of the structure and operation of this engine with considerable fulness of detail, and much of what we say will also be found to illustrate the merits of the other varieties of engine. Of the side lever marine engine, the engines of the City of London steamer, by Mr. Robert Napier, plate 12, may be taken as an illustration. We may take this engine as a text to suggest the few remarks upon side lever engines we here desire to record, postponing to a more advanced stage of our progress, (pages 215 to 230.), any extended enquiry into the details of that description of engine.

The framing shown in plate 12. is of malleable iron. This is a wise innovation, for it was a difficult thing to prevent cast iron framing from being broken by the working of the ship, though we believe Mr. Robert Napier's framing was more exempt from such accidents than that of any other maker. This malleable iron framing is a judicious one; yet we think it might have been an improvement if the diagonal stays had run on to the cylinder, the parallel and valve motion shafts being supported on a column tied to the diagonal stay by a bar running from the top of the column to the junction of the lower diagonal stay, with the crank shaft pillar adjoining the air-pump. The piston rod is secured into the cross head with a nut on the top, as well as a cutter through, which is a good practice. There is too little taper in the part of the rod which fits into the cross head, so that it will jam, and cannot be got out without great difficulty in the event of such disconnexion being wanted. There is also too little taper in the piston-rod where it passes through the piston, though there is a counter-sink to take the strain, which will prevent the piston rod from splitting the piston. If the cone on the piston rod end be made slight, and nothing be added to take the strain, the rod will be drawn up through the hole, and the piston will be split: this accident has happened to several of Mr. R. Napier's pistons. The piston packing consists of a double tier of rings. We think a single ring turned, of an eccentric form, and fitted with a tongue-piece, to be a preferable packing.

The valve is of the long D variety, of which we do not approve much for large engines, and the method of packing it is not convenient. There are no packing ports formed in the back of the valve casing, but the packing has to be put in from the inside, and the valve has to be drawn every time that it is packed. It is a defect we conceive for the eduction passage to enter the condenser at so low a level. The faucett joint in the valve casing is a good arrangement, and ought to be applied to all engines above a moderate size. The air-pump bucket is unprovided with a junk-ring for screwing down the packing, the want of which is, in large engines, a weighty fault. The bucket valve is of the common pot-lid description, which strikes hard. There are two delivery valves, one in the mouth of the pump, and the other in the hot well. We do not see the use of this multiplication, especially when there are engines working well without any delivery-valve at all. The same objection that we brought against the want of sufficient cone in the ends of the piston rod applies also to the air-pump rod. The connecting-rod is needlessly heavy: the connecting-rod at the smallest part need not be so thick as the piston rod, and here it is much thicker. The starting gear in the City of London, consists merely of a long lever, by which it is difficult to obtain sufficient power for moving so large a valve: a great number of men are required to start the engine, and the travel of the starting lever is so great, when the engine is thrown into gear, as to be a source of danger to persons in the vicinity. This is not a common fault of Mr. R. Napier's engines; in the engines of the Precursor, the starting gear is the most elegant and convenient that has come under our observation; and the engines of the City of London, notwithstanding the slight imperfections we have mentioned, are sound and good engines in most respects, and will, we have no doubt, cost but little for repair. In the Precursor and British Queen steamers, the engines of both of which vessels are by Mr. R. Napier, the starting gear consists of a wheel, like the steering wheel of a ship, which, by means of a pinion working into a sector on the valve-shaft, gives motion to the valve, and the power is thus so multiplied that one man can start the engines. To prevent inconvenience from being experienced by the engineer from the rapid whirling round of the starting-wheel, when the engines are thrown into gear, the disconnecting apparatus it is so contrived that the act of throwing the eccentric rod into gear, throws the starting wheel out of gear, and *vice versâ*. In the Precursor the eccentric rod is thrown out of gear by means of a lever, with a pulley on the end of it, and which, being forced up against the under side of the eccentric rod, lifts the rod out of a notch. The centre of this lever is attached to an eccentric stud in the framing, which is so contrived, that when the lever is in the position which allows the eccentric rod to fall into gear, the eccentric stud draws back the valve-shaft, so that the teeth of the pinion are no longer in gear with the teeth of the sector; but when the lever is forced up into the position which throws the eccentric rod out of gear, the valve shaft is pushed forward until the connexion of the pinion and sector is again established. It is very desirable that this or some equivalent contrivance should be adopted in all engines where the starting handle has a large travel, as the rapid movements of the starting handle, when the engine is thrown into gear, will otherwise be a source of much danger to the engine attendants.

The engines of the steamers Clyde, Tweed, Tay, and Teviot, plate 13, by Messrs. Caird and Co., are clear of many of the defects which we have just mentioned, but they have others of their own. Of these, the most remarkable is the obstruction offered by the valve to the entrance of the steam into the valve casing, when the valve is at the lower part of its stroke, so that during the upward stroke of the piston the steam is effectually throttled. This, of course, was an oversight of construction, but it is one that must seriously impair the efficacy of the engines. The diagonal stay appears to be too weak where it joins the cylinder. It is a bad plan to have the main centre going through the condenser, as it is difficult to keep the joint tight, unless a pipe be cast in for putting the main centre through; and if that be done, the inequality of contraction in the metal makes the sides of the condenser very liable to be cracked, by heating with steam in blowing through, and cooling with cold water when the injection is admitted. Many of Messrs. Caird's condensers have been cracked in this way. It appears to us preferable to make the condenser in the form of a large and tall pipe, the main centre being supported by pillow blocks of a suitable construction; and this is the plan followed by the London engineers in their side lever marine engines.

Paddle-wheels. If a body moves through a quiescent fluid with a given velocity, or if a fluid moving with a given velocity impinge against a body at rest, the resistance will in either case be as the square of the velocity, while the power requisite to overcome that resistance will be as the cube of the velocity; so that if the velocity of a steamer be doubled, the resistance experienced in passing through the water becomes four times greater than before, and the power required to achieve that doubled speed eight times greater than before. This is explained by the circumstance that the resistance of a body moving in a fluid is proportionate to the number of particles struck and the velocity with which they are struck: as twice the number of particles are struck, and each particle with twice the force, there is four times the resistance; and as the strain occasioned by this resistance is four times greater upon the engine, and the engine has at the same time to work at twice the speed, there must be four times the expenditure of power. If the surface of the resisting body be denoted by unity, and d denote the density of the fluid, r the resistance which it opposes to the motion of a solid body, and v the velocity of motion; then, universally, r is as $d\,v^2$, and if a denote the area of the plane, r is as $a\,d\,v^2$.

The absolute resistance which a quiescent fluid opposes to a plane surface moving through it with a given velocity, is equal to the weight of a column of the fluid whose base is the plane, and altitude the same as that which is due to the velocity of motion; that is, the height through which a heavy body must fall to acquire that velocity by the action of gravity. Putting a for the area of the plane of impact in square feet; h, the height through which a heavy body must fall to acquire the velocity by the action of gravity; r, the resistance offered by the fluid to the motion of the plane; s, the specific gravity of the fluid; v, the velocity of motion in feet per second, and g, 32⅙ feet, the constant coefficient for gravity: then, as r is proportional to $a\,d\,v^2$, or what is the same thing, $a\,s\,v^2$, and as r is also by the proposition equal to $a\,h\,s$, while h, by the laws of falling bodies, is equal to the square of the velocity divided by twice the power of gravity, we have $r=\frac{a\,s\,v^2}{2\,g}$ and as the weight of a cubic foot of river water is 62½ lbs. we have $r=\frac{62\frac{1}{2}\,a\,v^2}{2\,g}$ and by restoring the numerical value of $2\,g$ we get

Resistance = area × velocity squared × 0·9715.

To ascertain the resistance in horses power we must take one minute for the unit of time, multiply the coefficient by 60 times the velocity in feet per second, and divide by 33,000. The equation then becomes—

Resistance in horses power = area × velocity cubed × 0·00176637

This expression, however, though fairly representing the resistance in horses' power, or the number of horses' power necessary to impel at a given speed such vessels as the Medea and others of the same stamp, will not apply in the case of very sharp vessels, and indeed a new co-efficient is necessary for every different shape. The Medea has an immersed sectional area of 263 square feet, and is impelled at the rate of 11·33 English miles an hour, or 16·61733 feet per second. $16{\cdot}61733^3 \times 263 \times 0{\cdot}00176637 = 2131{\cdot}675$ horses' power, so that 2131 horses' power would be required to force a plane with an area of 263 feet through the water at the rate of 11·33 miles per hour. The power of the Medea, however, is only 220 horses, and of this about one third is lost by the slip of the wheel leaving only 146 horses' power available for her propulsion, so that the shape of the vessel has the effect of reducing the resistance from 14·6 to 1. With a better shape there will of course be a still larger reduction.

When a fluid impinges upon a plane surface in an oblique direction, it will impel the plane in a direction at right angles to its surface with a force which is proportional to the square of the velocity of motion, the density of the fluid, the area of the plane, and the square of the sine of the angle of incidence. The equation for the resistance then becomes—

Resistance = area × velocity squared × sine squared of angle of incidence × 0·9715 and the resistance in horses' power stands thus:—

Resistance in horses, power = area × velocity cubed × sine squared of angle of incidence × 0·00176637.

When a paddle wheel is first put in motion, every point upon it describes a circle round the centre; but as the vessel begins to move, the forward motion of the vessel being compounded with the rotative motion of the wheel, each point describes in the air or water a curtate cycloid differing from a circle in the proportion of its propinquity to the centre. The speed of the vessel is usually about a third less than the speed of the extremities of the paddle arms, and a circle therefore described on the wheel with a radius of two thirds the length of the paddle arm will travel with the same speed as the vessel passes through the water. This circle, which is usually called the rolling circle, is such, that if the vessel were travelling upon land upon wheels of that size, and with the same speed of engine, her velocity would remain unaffected. If d denote the diameter of the rolling circle in feet, m the velocity of the vessel in English miles per hour, and n the number of revolutions of the wheel per minute, we have 5280 m for the motion of the vessel in feet and 60 n for the number of revolutions; so that $\frac{88\,m}{n}$ is the circumference of the rolling circle, and its diameter is $\frac{88\,m}{n\,\pi}$.

As every point in the radius of the wheel moves with a greater velocity as it is further from the centre, it is clear that the portion of the paddle board furthest removed from the centre must experience a different degree of resistance from the portion nearer to it; and the mean centre of pressure therefore cannot be at the centre of the float, but at a point nearer the outer edge, and varies also with the angle of the paddle and the depth of the immersion. For light immersions it may be reckoned that the resistance on any point of the paddle board varies as the 3d power of its distance from the rolling circle: and assuming this, let us put R for the radius of the wheel estimated from the centre to the outer edge of the paddle board; r, the radius of the rolling circle; δ, the depth of the paddle board; x, any variable distance estimated from the upper edge of paddle board; and y, the distance between the upper edge and centre of pressure. Then $(R-r)$ is the difference between the radius of the wheel and that of the circle of rotation; consequently the differential of the resistance becomes $\{(R-r)+x\}^3\,d\,x$, and its integral is $\{(R-r)+y\}^3\,\delta$; and by reduction we arrive at the following rule: From the radius of the wheel subtract the radius of the rolling circle; to the remainder add the depth of the paddle board, and divide the fourth power of the sum by four times the depth; then from the cube root of the quotient subtract the difference between the radii of the wheel and circle of rotation, and the remainder will be the distance of the centre of pressure from the upper edge of the paddle. Instead of the common radial paddle-wheel, a description of wheels with moveable floats, known as Morgan's wheels, are now much employed, though they were for many years regarded with disfavour. In this wheel each paddle, which is of iron, is hung upon a centre in the manner of a throttle-valve, and is connected by a rod to a fixed eccentric, either on the side of the ship, or upon the spring beams which sustain the end of the paddle-shaft. When the wheel revolves the operation of the eccentric maintains every float in the vertical position, or nearly so, whereby a more perfect action of the wheel is realized than if the floats were fixed, as in the case of the common radial paddle with wooden floats.

In considering attentively the action of the paddle wheel, it will be remarked, that although the circular velocity of the wheel is uniform, very unequal portions of the cycloidal path are described in equal times; for the space described during the first quadrant is more than double that described during the second, and that described during the third quadrant is less than half that described during the fourth. The result of this action is, that the vertical paddle board, instead of being the most effectual in the propulsion of the vessel, as might appear on a cursory survey, is the least effectual of the floats immerged: for the horizontal velocity of a float when in the vertical position, is at its minimum point, and consequently in the common radial paddle wheel both the entering and emerging floats are the more effectual. In the feathering paddle this action is materially modified, and the feathering paddles do not involve the same loss of power. By rendering a smaller diameter of wheel applicable, too, they enable the engines to move at a higher speed, whereby their efficacy is increased: a vessel that will go 13 miles an hour with the common wheels, will make a mile an hour more with the feathering wheels, the power of the engines being the same in both cases.

Much prejudice at one time existed to the use of feathering paddles in the case of sea-going steam vessels, and not altogether without reason, as in several instances the paddle wheels were so insecure that they were entirely swept away by the sea. But this fault was one merely of construction, and in the wheels made by Messrs. Penn, and latterly too by several other makers, no defect of this kind has arisen, while the speed of the vessel is certainly materially greater than if the ordinary paddle-wheel had been adopted. The constructive expedients employed by Morgan were in many respects very defective; but the wheel as now made is probably as strong as many examples of the common wheel, and while it gives a better result, it is of much more convenient dimensions. The benefits derivable from feathering floats, however, will not be realized to any appreciable extent, unless the wheel be kept very small in diameter, for it is then alone that the engine can get away at a rapid speed, and it is from the superior speed of the engine, rather than from any other cause, that the benefits due to the feathering action are attributable. Wheels of the common radial kind cannot be made small in diameter without involving such a disparity in the effect of the entering and vertical floats, as to occasion a material loss of power; added to which, the entering floats, if far up on the arc of the wheel, will carry a wave before them in the same manner as the bow, whereby an additional loss of effect will be occasioned. Upon the whole, it appears expedient that paddle-wheel steamers should have their floats made on the feathering plan; and a very perfect specimen of this kind of wheel is given in the views of the machinery of the Black Eagle steamer by Messrs. Penn, represented in Plates 18. and 19.

DREDGING.—An application of the marine engine of some importance is to the purpose of dredging, and we here give the heads of the specification of a dredging machine planned by Mr. Locke for the Greenock Harbour Trust:—

Bucket Ladder.—The ladder shall be 36 ft. long between the centres of the tumblers. The details of this ladder are shown in the drawing, and the following are a few of the principal dimensions. The main beams shall be oak, each 32 ft. 8 in. long, 12 in. deep, and 6 in. thick, placed 2 ft. 3½ in. apart; four cross ties of oak must be placed between these beams and morticed into them, each 12 in. × 6 in., and in the positions shown in the drawing. Each of these main beams shall have 3 in. of camber. These main beams shall be trussed by a beam of oak, 6 in. × 6 in., in the form shown in the drawing. Between the main beams and the curved beams, struts 6 in. × 6 in. must be placed, in the positions shown in the drawings, and properly morticed into the beams. Between the two curved beams cross pieces of timber shall be placed where shown in the drawing. At the ends of the ladder where the beams join, chock pieces, 6 in. thick, and reaching 6 ft. 6 in. from the ends, must be placed. The two beams must be dovetailed into these chock pieces, and all firmly bolted together. The extreme depth of the ladder at the middle must be 3 ft. 9 in., and at the ends 1 ft. 3 in., the whole formed of oak.

Sockets. — Two malleable iron tie sockets for the ends of the beams must be furnished; they shall be 3 ft. 6 in. long and 1 in. diameter; and must be placed one on each side of the oak ties between the main beams.

Iron Truss Rods. — The ladder must be trussed by two rods of 1¼ in. round iron; each rod must have a box screw for tightening it.

Hinges. — Two malleable iron hinges must be fastened to the top of the bucket ladder; they shall be 8 ft. in extreme length, and 1⅜ in. thick; the head of the hinge must be 20 in. diameter, and the hole for the hinge shaft bored to 13 in. diameter. The arms shall be 8 in. broad, with four slots, 8 in. long, in each. These hinges must be bolted to the beams, as shown in the drawing.

Arms at Lower End of Ladder. — Two malleable iron arms, 7 ft. 9 in. in extreme length, must be fastened to the lower end of the bucket ladder. They must have four slots, 8 in. long, and be bolted to the beams; the lower end to be fitted with straps, cutters, gibs, and brasses. Each strap must be furnished with a strong shackle for the hoisting chains: an extra hole must be left for the pin of the shackle, so that it can be shifted when required. The part of the arms where the shackle is fixed shall be 8 ft. 3 in., as shown in the drawing.

Tumblers. — A cast-iron tumbler must be fastened on the upper end of the bucket ladder, 2 ft. 5¼ in. long, and 1 ft. 8 in. square, with a malleable iron flange, 2 in. square, shrunk on at each end. The metal in the sides must be 1⅜ in. thick, and the tumbler must have four snugs, as shown in the drawing. A cast-iron tumbler is also required for the lower end of the ladder, 2 ft. 9 in. long, and 1 ft. 8 in. square. It must be bevelled off 3 in. at the ends, as shown in the drawing. Two opposite sides of this tumbler must have snugs cast on them, 14 in. long, 3 in. high, and 2¼ in. thick; these snugs must be 10 in. apart. The metal in the sides shall be 1¼ in. thick.

Tumbler Shafts. — A malleable iron shaft, 8 ft. 1 in. long, and 6 in. diameter, is required for the upper end of the ladder. It must have key seats, of 7 in. diameter, for the tumbler and bevel wheel; and two journals, 9 in. long, and 6 in. diameter, and 5 ft. 1 in. apart, as shown in the drawing. A malleable iron shaft is also required for the tumbler at the lower end of the bucket ladder. It shall be 3 ft. 10 in. long, and 5 in. diameter: it must have two journals, 4 in. long, and 3 in. diameter, and 3 ft. 3¼ in. apart.

Rollers for Pitch Chains. — Eight cast-iron rollers are required for the pitch chain to run upon; they shall be 2 ft. long, and 7 in. diameter. They must have square spindles of malleable iron, of 2 in. diameter, at the journals. Two cast-iron pillow blocks are required for each roller; they must be sunk 1½ in. into the beam, and firmly screwed down. The centres of the rollers shall be 4 in. above the ladder.

Pitch Chains. — Two malleable iron pitch chains are required for the bucket ladder. Each chain shall have 40 links and 40 joints, 20 single links and 20 double links: each link shall be 2 ft. long between the centres, and 2 ft. 5¼ in. long over all; the links shall be straight on the top and bottom; they shall be 3¼ in. deep, by 1⅜ in. thick, except at the joints. The pins for the joints shall be of steel, and turned to 1⅜ in. diameter, with round heads, 2¼ in. diameter; they shall have washers, ¼ in. thick, and be fastened at the end with cutters, 1 in. wide, and ¼ in. thick.

Buckets. — There shall be twenty buckets, made of malleable iron. The buckets shall be made of ⅜ in. boiler plate. The underside of each bucket next to chain shall be flat, and 1 ft. 8 in. square, the bottom 8 in. high, and the mouth 1 ft. 8 in. high. The greatest width at the mouth shall be 2 ft. 5¼ in. The upper side of the bucket shall be 2 ft. long, and curved across, as shown in the drawings. The mouths of the buckets shall have a piece of iron, 3 in. broad, and 1 in. thick, rivetted round the outside; and they shall have also a piece of steel welded around the edges. The bottoms and sides of the buckets shall be pierced with 12 holes each (24 in all). All these dimensions are inside measurements.

Fixing of Buckets. — Each bucket shall be fixed to the double links with four pieces of 3 in. angle iron, each 15 in. long. These pieces of angle iron shall be rivetted to the sides of the links and to the bottom of the bucket.

Pedestals at Upper End of Bucket Ladder. — There shall be two pedestals for the pillow blocks of the tumbler shaft at the upper end of the bucket ladder. They must have branches for supporting the bucket ladder, as shown on the drawings. Each of these pedestals shall be 13 in. high, besides snugs, 3 ft. 7 in. long on the sole, 2 ft. 9 in. long at the top, and 9 in. broad. Each branch shall have a ring projecting 2 in., and turned up to 13 in. diameter, for the hinge of the ladder. There must also be a hole, 9 in. diameter, through which the shaft of the upper tumbler passes, as shown on the drawing. A flange, 1 in. thick, 2 ft. 3 in. long, and 11 in. deep, must be made on each side of the pedestal under the branch, and bolted to the top of the beams, as shown on the section. The sole of the pedestal shall also be bolted to the top of the beams. These pedestals shall be cored, but the metal shall in no part be less than 2 in. thick. Two pillow blocks shall be made for the upper tumbler shaft. They shall each be 9 in. wide, 2 ft. 4 in. long on the sole, and 9 in. long from the sole to the centre, making the centre of the shaft 1 ft. 8 in. above the top of the beams. The buckets shall work at a speed of not less than equal to emptying 17 buckets per minute.

Main Shaft. — The main shaft shall be of cast iron, and 45 ft. 3 in. long, and 7 in. diameter. It must be in five lengths, with three circular couplings and one disengaging coupling, with a lever for throwing it in and out of gear, as shown on the drawing. The centre of this shall be 10 in. from the side of the well, and 1 ft. 8 in. above the top of the beams. The journal shall be 7 in. diameter, and 9 in. long.

Pedestals for Main Shaft. — Five pedestals shall be formed for carrying the main shaft, as shown on the drawing. They shall be 2 ft. 3 in. long, and 9 in. broad. They shall have arms or flanges below for embracing the beam, 11 in. long on one side, and 2 ft. long on the other. They shall be bolted to the beam and posts, as shown on the drawing. These pedestals shall be cored, but no part of the metal shall be less than 1 in. thick.

Wheels. — The following wheels and pinions are required. A bevel wheel on the upper tumbler shaft, 59·87 in. diameter on the pitch line; it shall have 50 teeth, 3¾ in. pitch. A bevel pinion on the end of the main shaft, 29·82 in. diameter; on the pitch line it shall have 25 teeth, 3¾ in. pitch: these wheels to be of unusually strong dimensions. A cog wheel on the end of the main shaft, 70 in. diameter; it shall have 88 teeth, 2¼ in. pitch: this wheel must have a friction socket, the details of which are shown on the enlarged sketch, No. 2. An intermediate wheel, 5 ft. 4¼ in. diameter, and 2¼ in. pitch. A spur pinion on the crank shaft, 39 in. diameter, 49 teeth, 2¼ in. pitch.

THE SCREW PROPELLER. — There is too little yet known respecting the performance and manner of operation of the screw propeller to justify the formation of rules pretending to regulate the details of practice; but the conviction of the most experienced engineers appears, at the present time, to be, that while for river steamers the feathering paddle is the best propeller, the screw has, at least, established a claim to equality in the case of ocean steamers; while as a propeller for vessels fitted with auxiliary power it has an undisputed superiority. The competition railways are now establishing to lines of coast navigation makes it certain that the ordinary paddle-wheel vessels must be superseded by vessels provided with auxiliary power, which are capable of being worked at a greatly diminished expense: and this circumstance appears calculated to give an importance to the screw as a propeller, it could not have otherwise obtained. For vessels of war the screw has the manifest recommendation, that it is less exposed to shot, and the whole of the machinery for driving the screw may be placed under the water line, which is not possible in the case of paddle-wheel steamers; but this point of superiority is not of dignity enough of itself to claim much attention, and to the superior applicability of the screw in conjunction with auxiliary power, its growing importance as a propeller is chiefly to be ascribed.

The form in which the screw propeller was first applied to the Archimedes steamer consisted of a broad helical feather attached to a cylindrical axis, driven by the engine, and which, working in the water in nearly the same manner as a carpenter's screw works in a piece of wood, carried the vessel forward in the direction of its length. The helical feather made a single convolution round the axis, the length of the convolution being regulated by the pitch of the screw; but this arrangement was relinquished, as it gave a vibratory motion to the boat, interfered with the action of the rudder, and threw the strain too much on one side of the axis; and two half convolutions of a double-threaded screw were adopted, instead of the whole convolution of a single-threaded screw. In later applications the screw has been made much shorter than what answers to half a convolution; about one-sixth of a convolution is now a common proportion. In the Great Northern, the area of midship section at 16 feet draft of water is 540 square feet, while the screw contains about 90 square feet, deducting the area of the boss. The speed of the vessel is nine statute miles an hour, and the slip of the screw is one tenth.

If, when the vessel is at rest, the engine causes the screw to revolve on its axis without advancing forward in the water, every point of its surface will describe a circle, the magnitude of which is proportional to the distance of the describing point from the centre of motion. It is clear the surface of the screw will strike the water with a force that is due to the velocity of motion, and the water will be impelled in a direction at right angles to the surface, with a velocity corresponding to that of the revolving feather, but varying in proportion to the distance of any particular point from the axis. This is the force that is effective in propelling the vessel, and it will be seen that it is greater, at a greater distance from the centre, decreasing gradually as we approach the axis where the velocity of the revolving surface is small. On the other hand, if the vessel moves forward in the direction of its length while the screw is prevented from revolving on its axis, every point on the surface of the projecting feather will trace a straight line, equal in length to the distance passed over by the vessel; or, in other words, the screw, in being pulled forward, will displace a cylinder of water of its own diameter and of the length of the vessel's motion, occasioning, of course, a waste of power in the operation. When the screw is put into action by the engine, both of these resistances are encountered. If the action of the propeller were perfect, the screw would operate as if working in a nut; and as there would be then no loss by slip, we could ascertain the speed of the vessel by multiplying the number of revolutions by the pitch of the screw, and dividing by 88, which would give the speed per hour in statute miles; but in practice the speed is generally from one-tenth to one-twentieth less than the speed thus ascertained. There is not an invariable loss by slip, however, or at least not an apparent loss, for in some cases, the vessel is propelled at a faster rate than if the screw worked in a solid. One cause of this anomaly probably is that the water in closing in upon the wake of the vessel having a motion given to it, the screw impinges, not upon still, but upon moving water, whereby an increased reaction is obtained; but something depends too upon the size of the screw, and in general it has been found that when the superficial area of the screw, taken as a disc, is about one-fourth of the area of the immersed section of the vessel, the speed will be as great or greater than if the screw was working in a solid. The water partakes very little of the rotatory motion of the screw, but is drawn in on all sides from the circumference towards the centre, and is then projected aft in a column slightly conical, as it recedes from the screw. The pitch of the screw, or the angle at which the blades are set, differs necessarily with the form of the vessel and the power of the engine, or, in other words, with the speed expected to be attained: a common enough angle is from 66 to 68 degrees with the axis.

In settling the dimensions and pitch of screw proper for any particular vessel, the first indication is to make the diameter of the screw as large as it can be got; and then the probable speed of the vessel, judging from the power and form, is to be estimated, which, after fixing the number of revolutions and making an allowance of say one tenth or one twelfth for slip, will give the pitch of the screw. Most of the screws now used are made with two threads, or have two blades. Screws with three blades act more equably, as the whole of the blades are never in the line of the stern-post at once, at which point the forward thrust is greatest; but double-threaded screws seem upon the whole to be the most effective, and they may, if necessary, project beneath the keel, as they can be turned into the horizontal direction when the vessel is in harbour, to prevent them from touching the ground. To ascertain the amount of helical surface of a screw making one convolution: multiply the sum of the radii of the screw and of the central boss by their difference, and the product will be the difference of their squares: multiply this number by 3·1416, and the product by the secant of the angle of the screw, and the result will be the area of the helical surface sought.

Bourne's Patent Double-power Engine.—The screw propeller has created a new exigency in steam mechanism. The propeller generally requires to make a greater number of revolutions than the engines can conveniently perform; and cog-wheels have in many cases been introduced to bring up the speed, thus introducing into steam vessels the jar, tremor, and liability to fracture incidental to the use of such devices. To remove this source of objection it is necessary that the engines should be coupled direct to the propeller shaft; but as the valves of the air-pumps would strike so hard as to knock themselves to pieces if the engines were worked at any very high speed, and as the various contrivances of canvas and Indian rubber valves are of doubtful efficacy in such an emergency, Mr. Bourne has contrived a species of engine in which the whole of the air-pump valves are replaced by a particular arrangement of slide valve, whereby the engine may be worked at any degree of speed without inconvenience. One effect of this innovation is to make engines work more noiselessly than before, as there is no longer any shock, such as that which attaches to the action of the foot and delivery valves and the valves of the air-pump bucket in common engines. But the most important feature of the arrangement is, that by enabling the engines to work at twice the ordinary speed, it enables them to exert twice the ordinary power. It is not for screw vessels alone, therefore, that such engines are appropriate, but they may be applied with advantage to most of the purposes for which steam power is required. In the case of mill engines they possess the recommendation of imparting a more equable motion to the machinery, and in other cases they may be so arranged as to save fuel by permitting a larger expansion than could be allowed with a lower speed. Engines on the double-power plan can be sold for a less sum per horse power than engines upon the common plan with the same quality of workmanship and materials; and as the double-power engines are more compact, and for most purposes more convenient than the ordinary engine, it appears probable that they will come into general use. In the case of mine engines, Mr. Bourne proposes under certain circumstances to apply a centrifugal pump to the condenser for the discharge of the water. It is obvious that the air-pump valves could be dispensed with by such an arrangement; but it is equally clear that in ordinary cases the application would not be successful, as the centrifugal pump, though it discharged the water, would not discharge the air; and even if a pump were applied to extract the air, the objection would still remain, that at low rates of speed the centrifugal pump would be inoperative. Another inconvenience of the centrifugal pump is, that it requires to be driven at a very high speed; but in the case of mines drained by the centrifugal pump, the injection water can easily be got rid of by leading it down to a depth of 32 feet, when it will run off by gravity, and be returned by the centrifugal pump to the surface; and in such a case the only function of the air-pump will be to draw off the air and vapour. Mr. Currie, of 11. Savage Gardens, London, who manufactures the double-power engines, thus speaks of their recommendations:—

"Mr. Bourne's double-power engines, which I manufacture, both on the high and low pressure principle, and for all the uses of mines, mills, and steam navigation, I consider certain to introduce a new epoch into the history of the steam engine, as it is impossible but that the ordinary engine should be superseded by a new engine the advantages of which are so conspicuous. A double-power engine is only half the weight of a common engine, occupies only half the space, and costs but little more than half the money. It works more smoothly than a common engine, and for the purposes of cotton-spinning has the great advantage of giving a more steady and uniform motion to the machinery. When applied to screw vessels, it dispenses with gearing, and saves weight and space in the ship. The smaller powers of engine, for which there is an increasing demand, are so light and compact, as compared with common engines, that they excite universal wonder and some incredulity as to the realization of the power; but I warrant every engine I send out to be capable of exerting *twice* its nominal power as determined by Watt's standard. In the smaller powers the engine is set upon the top of the boiler, which is a tall cylinder about the size of a tolerably large stove: the chimney is of sheet iron, into which the waste steam passes, and the engine may be set to work a quarter of an hour after it leaves my warehouse, as all the fixing it needs after being set in its place is the screwing up of a few bolts to hold it down. For farm purposes the engine and boiler may be set upon wheels, and thus be transported readily from place to place." This statement is probably to be received with some qualification, as Mr. Currie cannot be regarded as a wholly disinterested witness. Nevertheless the facts appear indisputable that engines upon the double-power plan are lighter, more compact, and less costly than common engines; and these are points of superiority which cannot fail to tell or to be discerned.

Mr. Currie furnishes the following further particulars relative to this engine:—"The boiler of the double-power engine is for the most part constructed with upright tubes, and I generally set the engine upon the boiler in all powers under 40 horses. The following are the chief dimensions of a one-horse power engine and boiler:—Diameter of boiler, 16 inches; height of boiler, 40 inches; diameter of furnace at crown plate, 12 inches; diameter of furnace at bars, 13 inches; height of crown plate above bars, 12 inches; depth of fire bars, 2 inches; depth of ash-pit, 4 inches; depth of smoke-box, 4 inches; diameter of chimney, 3 inches. There are 36 tubes in the boiler, 1 inch in diameter, and 16 inches long; but 12 inches in the length of tube only passes through the water, and is alone counted as effective: the thickness of the shell of the boiler is three-sixteenths; and the pressure the boiler is calculated to bear is 80 lbs., though 70 lbs. is the working pressure. The diameter of the cylinder is 2 inches; length of stroke, 3 inches; number of revolutions per minute, 872; number of feet travelled by the piston per minute, 436; and though these dimensions are small, that they will give fully a horse power is made manifest by a simple calculation. The area of a cylinder 2 inches in diameter is 3·1416; and if the effective pressure be taken at 60 lbs. per square inch, instead of 70 lbs. (as a compensation for friction and loss of effect from radiation and expansion), we have a force of 188½ lbs. urging the piston at a speed of 436 feet per minute, which is equivalent to 82,184 lbs. raised one foot high in the minute; and dividing by 33,000, this gives us about 2½ horses' power. It is clear, therefore, that this engine, notwithstanding the smallness of its dimensions, will give a power more than twice as great as the horse power of Watt, provided, of course, it is abundantly supplied with steam, and the supply of steam depends upon the amount of heating surface in the boiler, which requires to be as great in this as in any other boiler exerting the same power. On calculating the amount of tube surface, it will be found to amount to 12 square feet, and the furnace surface will amount to about 3½ square feet more, making a total of 15½ square feet of heating surface per horse power, which is a large allowance. The weight of the boiler is about 2¾ cwts., and the total weight of engine and boiler, with water in the boiler, is about 4¼ cwts.

"Of the 40-horse power engine and boiler on the double-power plan, the following are the principal dimensions:—Diameter of boiler, 4 feet 8 inches; height of boiler, 8 feet; diameter of furnace at crown plate, 4 feet; diameter of furnace at bars, 4 feet 1 inch; height of crown plate above bars, 20 inches; depth of fire bars, 4 inches; depth of ash-pit, 8 inches; depth of smoke-box, 12 inches; diameter of chimney, 12 inches. There are 547 tubes 1 inch diameter, and 52 inches long, of which a length of 34 inches only passes through the water, and is alone reckoned as effective. The thickness of the shell of the boiler is half an inch, and the plates are all double rivetted; the pressure which the boiler is calculated to withstand is 80 lbs. The diameter of the cylinder is 12 inches; length of stroke, 18 inches; number of revolutions per minute, 195; number of feet travelled by the piston per minute, 586. The area of a cylinder 12 inches in diameter is 113·097 square inches; and if we take the effective pressure as before, at 60 lbs., we have a force of 6785·8 urging the piston at a speed of 586 feet per minute, which is equivalent to 3,976,490 lbs. raised one foot high per minute, which, being divided by 33,000, gives 120 horses' power, which is just three times the nominal power. The weight of the boilers is about 61½ cwt.; and the total weight of engine and boiler, with water in the boiler, is 90 cwt., or 2¼ cwt. per horse power.

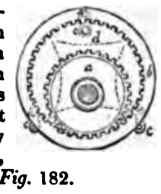
"The engine is of the oscillating kind, and the shaft, crank, and framing for supporting the crank, are all of polished malleable iron; the fly-wheel is very small, and is made with a polished rim, which also answers for the drum upon which the belt runs that carries away the power. The governor is made in the usual manner, but is, of course, so proportioned as to be adapted to the higher speed at which the engine travels. The waste steam passes into the chimney, as in locomotive engines, whereby the draught is so quickened that a small area of grate bar suffices; but the end of the eduction pipe entering the chimney is never contracted, as in locomotives, as any contraction of the eduction pipe produces a loss of power. In the larger class of engines a platform is attached to the boiler, to make the engine accessible to the engine-man, thus obviating the necessity of any peculiar structure in the engine-house; and for exportation to tropical climates, the engine-house is itself made of sheet iron, and needs only a few screw bolts to connect the several parts together, to adapt it for the reception of the engine and boiler. The larger class of boilers are provided with Lamb's Scale Preventer, for which I am the sole agent, and which is a contrivance for blowing off from the surface of the water, whereby the impalpable particles of which scale is composed, and which are ballooned to the surface by bubbles of steam, are caught and ejected from the boiler, before they have had time to subside upon the flues. This scale preventer has already been applied by Boulton and Watt; John Penn and Son; Bury, Curtis, and Kennedy; Maudslay and Field; Miller and Ravenhill; Caird and Co.; Tod and Macgregor; and most of the other engineers, to various boilers constructed by them, and its efficacy has been amply tested by experience in various land boilers, and in the following steamers, Pottinger, Ripon, Pekin, Erin, Ariel, Haddington, Tagus, Pasha, Braganza, Montrose, vessels of the Austrian Lloyd's, and a multitude of others. The boilers of the double-power engine, with this addition, are not liable to the formation of scale.

Samuda's Bell Crank. — An engine with inverted cylinders is figured in Plate XV., under the title of Samuda's Bell Crank Marine Engine, where A is the framing, C the cylinder, D the condenser, E the air pump, *h* the air pump cross head, P the piston rod, J the connecting rod, K the paddle shaft, S the slide valve, and T the bell crank lever. By this arrangement, it will be observed, one crank suffices for the two engines. The plan of the engine closely resembles that adopted in the Gypsey Queen, but in that case the cylinders were not inverted. We think we can discern Mr. Clegg's hand in this combination, and it is one not unworthy of his ingenuity: nevertheless the arrangement requires considerable length in the engine space, and although it accomplishes a saving of width, yet width is not the dimension in which the size of marine engines most require to be contracted. The space left on each side would be only of little value, unless the boilers were placed there; and if that were done, their contiguity to the vessel would be dangerous, or at least injurious, in the case of wooden vessels, and would defeat one of the great objects of modern boilers — that of making every part of the shell accessible.

Galloway's Direct Action Engine.—This engine, represented in Plate XVI., consists of two steam cylinders, the piston and rods of which are attached by suitable links to a main cross head or beam, connecting both engines; forming a part of this cross head are two triangular frames of wrought iron, which, serving the double purpose of side rods and connecting rods, descend one on each side of the cylinders, and they are connected immediately with the cranks on the main shaft, lying between the cylinders in a line with the keel of the vessel. The air-pumps are worked by the same arrangement of levers which forms the parallel motion for the piston rods; the hot water and bilge pumps are wrought by the air pump cross heads in the usual way. The main shaft gives motion to the screw shaft through the medium of a new multiplying gear, a front view of which is shown in the drawing. The engines are of 300 horse-power, and every part of them is below the water line of the vessel.

There is extraordinary ingenuity in the whole of these arrangements; nevertheless this engine has not come into use, and we fear is not likely to meet with extended adoption. The mode of operation of the multiplying gear is not easily comprehended, but the principle of the arrangement may be explained to consist in such an arrangement of two cranks, of which the one is twice the length of the other, that the movement of the crank pin of the longer crank through a semicircle will cause the crank pin of the smaller crank to move through a whole circle. The principle, however, will be made more clear by an extract from Mr. Galloway's specification, which we therefore introduce.

Fig. 179.



"If the wheels shown in *fig.* 179. revolved upon axes in the usual way, *a* would make an entire revolution, whilst *b* made only some portion of a revolution; but if *b*, instead of revolving upon an axis, be suspended upon three cranks, *c*, *c*, *c*, of equal length, and the radii of which are respectively equal to one-half the difference between the diameters of the wheels (calculating such diameters from the pitch-lines); and if the whole apparatus be at first in the position indicated by the drawing, thereby causing *a* to revolve, it will be found that the cranks, *c*, *c*, *c*, and consequently their axes, will make three revolutions during the time that the inner wheel, *a*, makes one revolution. So if the proportionate diameters differ, say as 2 to 3, or 4 to 5, or any other integral proportions, and the lengths of the cranks *c*, *c*, *c*, be determined according to the rule I have given, then the cranks will always make as many more revolutions than the axis of *a*, as the diameter of the driving-wheel, *a*, is to the difference between the diameter of the two wheels.

Fig. 180.

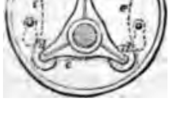


Fig. 181.

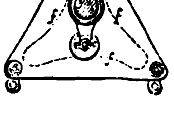
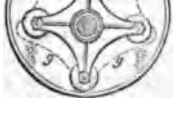


Fig. 182.



"But I propose, in most cases, as I have stated, instead of using toothed wheels, to adopt the arrangement shown in *figs.* 180, 181, and 182., which I shall now explain:—Let it be supposed that three equi-distant points (*d*, *d*, *d*, *fig.* 179.) could trace their path upon a plate or disc, attached to *b*, and moving therewith, such path would be four epicycloids dotted thereon; and if to the points *d*, *d*, *d*, three rollers, of equal diameter, were affixed, then a figure, *e*, *e*, *e*, *e*, *fig.* 180., would be the tangent of the said rollers in every part of their path; or, in other words, the rollers would trace out the figure *e*, *e*, *e*, *e*, *fig.* 180; such being the case, it will be manifest that if, instead of toothed wheels, we adopt the arrangement shown in *fig.* 180, where *d*, *d*, *d*, are the three rollers, affixed to arms, and revolving in bearings, and the figure *e*, *e*, *e*, *e*, whose interior curved aperture is generated upon the principle I have explained — then, on motion being given to the main axis, the cranks, dotted at *c*, *c*, *c*, will make three revolutions for one of the main axis; and if the figure *e*, *e*, *e*, *e*, be accurately constructed, and the cranks truly proportioned, the action of the machine will be comparatively smooth and noiseless. In like manner, if the circles or wheels, *a* and *b*, be in their diameters as 2 to 3, the figure *f*, *f*, *f*, *fig.* 181., would be generated, and by attaching the two rollers to the axis, as there shown, the velocity of the main axis would be to the crank axis as 2 to 1; or, if the diameter of *a* and *b* be as 4 to 5, the figure *g*, *g*, *g*, *fig.* 182., would be generated, and by constructing the apparatus, as shown at *fig.* 182., the relative velocities of the main axis and crank axis will be as 4 to 1. I would further observe, that in whatever proportion the multiplication be effected, it is necessary that the number of the rollers and of epicycloids should be respectively equal to the number of times the generating circles can be divided by the difference between the two diameters. It will also be manifest, that the multiplication effected by this method does not admit of fractional quantities, but must always be in integral proportions. I must further explain, that if one propeller only is intended to be used, one only of the three crank axes must be prolonged for that purpose; but if two propellers are intended to be applied, then two of the crank axes should be similarly prolonged. It is further necessary to explain, that the arrangement of this contrivance may be changed by attaching the driving axis to the epicycloidal figure, and the cranks to the part to which the rollers are attached; in which case the proportion of the multiplication will also be changed, so that the cranks of *fig.* 180. would make three revolutions instead of two; those of *fig.* 181. would make four revolutions instead of three; and those of *fig.* 182. would make five revolutions instead of four." This method of multiplying the speed of the screw shaft, though most ingenious, is likely to be rendered needless by the acceleration of the speed of the engine itself which is now taking place.

Direct Action Engines represented in Plate VII. — Direct action engines have of late years come into extended use in steam vessels, and their employment appears likely to become universal. They are less bulky and less weighty than side lever engines, and although most engineers resisted their introduction, these engines have now, even in the engineering world, risen to considerable favour. Most of the early devices were crude and unsatisfactory, but the excellent performance of the oscillating and double cross head engines have redeemed the class from the disgrace that might otherwise have been expected to overtake it. The existing crop of direct action engines is divisible into five varieties; the Gorgon, Siamese, Steeple, Double-cross-head, and Oscillating. We distinguish as Gorgon engines all those which have the connecting-rod between the piston-rod and the crank, whatever may be their subordinate features, and as Steeple engines all which have the connecting-rod situated above the crank. The Siamese, or Double-cylinder engine, is that employed by Messrs. Maudslay and Field and Messrs. Forrester, of Liverpool. The Double-cross-head engine is that adopted by Messrs. Bury and Co., Messrs. Fawcett and Co., and some others. The Oscillating engine is that brought into favour by Messrs. Penn, and which now numbers a multitude of admirers. Upon each of these varieties we shall have a few remarks to offer.

The objections to the Gorgon plan of engine are numerous and weighty. In the first place, only a very short stroke is attainable by this plan of engine; and although we are not of the number of those who subscribe to the doctrine, that expansion can only be productive of its proper efficacy in a long cylinder, yet we believe that an engine of a moderate stroke will work more steadily and smoothly than when the stroke is short, while the cylinder is of large dimensions. There is, moreover, a greater waste of steam at the ends of the cylinder when the stroke is short; and although the amount of this loss cannot be great, yet it is too great to be altogether disregarded. We do not attach the importance attributed by some to the deranging influence of a short connecting-rod upon the slide valve, but we attach a good deal of importance to the increased friction consequent upon the thrust, when the angle the connecting-rod makes is great,—not on account of the power absorbed, but on account of the difficulty of keeping the bearings from heating. To *this* objection it is no answer to say, that the friction of a direct-action engine is as little or less than that of a beam engine; the vice being, that the friction is not fairly distributed, but so concentrated at particular points as to be productive of injury in engines of the common proportions.

There is, however, a far more serious defect of the Gorgon variety of engine than any we have yet mentioned. It involves the use of a large paddle-wheel by the elevation of the shaft rendered necessary to afford room for the stroke; and the largeness of the wheel gives too great a velocity to the float boards, by which means a considerable proportion of the engine power is dissipated. There is nothing better known, than that in all cases where there is a great disparity between the speed of the wheel and the speed of the ship, a large amount of the power is wasted in throwing the water back from the wheel, instead of being employed in forcing the vessel forward; and in the Gorgon plan of engine, as applied to ordinary sea-going steamers, a serious loss from this source must be perpetually going on, or else the engine must be working under its proper speed and power. These objections apply to all short connecting-rod engines, of which the stroke is small and the shaft high; and in our eyes they carry sufficient weight to justify the condemnation of this species of engine *in toto.* As, however, there may be some persons, perhaps, who will not concur in this opinion, we shall here set down some remarks respecting the several varieties of Gorgon engine represented in the plate, with the view of further illustrating our convictions.

First in order, then, comes the plan of Messrs. Boulton and Watt, the engine represented being that of the "Centaur." In this plan of engine the condensers are situated between the cylinders, and at the extremity of each condenser an air-pump is situated. These air-pumps are wrought by a beam, the centre of which rests on the condenser top, and derives its motion from a crank on the intermediate shaft — a rod extending to communicate the movement from this crank to a pin near one of the ends of the beam, which is made something in the bell-crank fashion. The top of the piston-rod is maintained in the vertical position by guides.

There is much ingenuity in this plan of working the air-pumps, and the use of a beam enables the air-pumps to obtain an adequate length of stroke, without making the crank in the intermediate shaft of an inconvenient length; but the plan is attended with the very obvious objection, that if the beam breaks *both* engines are disabled; the beam, however, is of malleable iron. Messrs. Boulton and Watt have latterly resumed the use of the oscillating engine, of which engine Mr. Watt was, it appears, the inventor.

The next Gorgon engine in our list is that of Messrs. Miller and Ravenhill, the engine represented being, we believe, that of the "Eclair." This plan of engine takes up less room in the vessel than that last described; and, indeed, no engine can occupy less room than this, for its length is little more than the diameter of the cylinder. The condensers extend from cylinder to cylinder, having air-pumps within them, so that the whole of the cast iron part of the engine is bound together in a solid mass. The air-pump buckets are wrought by means of cranks on the intermediate shaft. This engine, while it is very compact, enjoys the advantage of two air-pumps, the fracture of either of which does not impair the efficacy of the other. In some of their very recent engines, Messrs. Miller and Co. have discarded the double crank in the shaft, and have wrought both air-pumps by one crank, the air-pumps being placed on the same vertical plane, and lying at an angle to permit this adaptation. This plan, which is the design of Messrs. Miller, is now adopted by Messrs. Penn, and others, and it is attended with several advantages. The water is brought very gradually up to the discharge-valves, on account of the angle at which the pump-barrels lie, and a softer action of the valves is thus obtained than if the pumps stood perpendicularly. Messrs. Miller have lately discontinued the Gorgon plan of engine, in favour of the oscillating kind, but have retained the inclined air-pumps, and have introduced other improvements; of these, the chief is the introduction of duplicate cylindrical slide-valves, standing on each side of the trunnion. These valves balance one another, and supersede the necessity of a balance to counteract the weight of the valves and valve-casing; nevertheless their action in practice has not been quite satisfactory. The valves, it is found, are very difficult to move, perhaps from a defect of workmanship, or some irregularity of expansion; but whatever be the cause, the fact is so. The valves also, from their small diameter, are not very accessible; and upon the whole their operation does not appear to be so satisfactory as the valve employed by Messrs. Penn, which leaves scarce anything to be desired.

We next come to the plan of Messrs. Fairbairn and Co., as applied on board the "Odin," of the engines of which vessel the view given in the plate is a representation. The general arrangement is judicious, and the framing, which, in all its main parts, is of malleable iron, is substantial and well adjusted. We think more favourably of the plan of a parallel motion for guiding the top of the piston-rod than the plan of the slides, for we believe the parallel motion may be more easily kept from heating. One great perfection in Messrs. Fairbairn's plan is, that the bearings of the parallel motion are made unusually large; and we feel assured that this engine will give less trouble to the engineer, and consume less oil and brasses, than are usually chargeable upon the Gorgon appetite.

The most of what we have said respecting Messrs. Fairbairn's engine will also apply to that of Messrs. Rennie, of which we entertain a very favourable opinion. The engines depicted as Messrs. Rennie's are those recently made for the "Samson." In this engine, Stephenson's link motion has been introduced to enable the engines to be quickly started or reversed, and its use is attended with complete success. Full speed ahead can instantly be changed to full speed astern; but if there be much lap upon the valves there is a certain position in which neither engine can get steam.

To Messrs. Seaward, we believe, belongs the merit of introducing the Gorgon genus of engine; and we trust this distinction may stand them in some stead, as the particulars of their arrangement, we fear, very much require some diversion in their favour. The length of this engine, it will be remarked, is very little less than that of the common side lever kind; so that we are thrown upon all the evils of a short connecting-rod and leviathan paddle-wheel, for the sake of a gain that is scarce worth having. In some of Messrs. Seaward's engines the evils of too high a shaft have, we understand, been very severely felt; and we learn that in the "Prometheus," which is fitted with these engines, the shaft has been considerably lowered, though at the expense of making the connecting-rod still shorter, that was inconveniently short before. The defect, however, of too high a shaft is, it must be remembered, not a peculiarity of Messrs. Seaward's variety of engine, but is a vice which attaches to the whole Gorgon tribe; and Messrs. Seaward's claim is therefore restricted to the merit of having carried the defect further than any one else has aspired to do.

We fear that much of what we have said respecting Messrs. Seaward's engine is applicable, also, to that of Mr. Robert Napier, which is not distinguished by any excellence answerable to his high reputation. Mr. Napier, we understand, approves more highly of the beam than of the direct action engine, and his preference is probably a just one, if the alternative be supposed to lie between the side lever and Gorgon varieties; but we are of opinion that both the Gorgon and side lever plans must be given up, and those manufacturers who adhere to them pertinaciously will gradually be deserted.

The last Gorgon engine we have to notice is, that of Messrs. Scott, Sinclair, & Co., the subordinate details of which manifest much judgment and ingenuity. The condensers and air-pumps are situated between the cylinders as in Messrs. Miller and Co.'s arrangement, but each air-pump is wrought by means of cross levers off the cylinder cross head of the other engine, whereby the necessity of cranks in the intermediate shaft is avoided, and each air-pump acquires the motion of the slide valve of its own engine, which is an advantage. To obviate any inconvenience from this arrangement in the event of fracture or other disarrangement, a passage is established between the condensers which may at any time be opened; so that an injury to one of the engines does not disable the other, as it would do without this provision.

The Steeple plan of engine, which is the invention of Mr. David Napier, has the merit of being very compact and effectual, and in the case of river vessels, offers advantages which have led to its extended adoption. The protrusion of a large portion of the machinery above the deck is, however, much objected to in the case of sea-going vessels, and Messrs. Tod and Macgregor now give the preference to the double cross head engines in such cases. It is a fault, we conceive, to make the air-pump with the same stroke as the cylinder. Where the air-pump bucket moves with a great velocity, the valves strike so forcibly as to wear themselves out very soon. The injury might, however, be mitigated by the use of the Cornish equilibrium valve, both for the delivery valve and the air-pump bucket, though of course in such case the equilibrium principle can only be applied so far as to *diminish* the force with which the valve shuts, not to obviate it altogether. The equilibrium principle, if carried far, greatly increases the load upon the pump; and this is the objection to the Cornish practice.

Of Messrs. Maudslay's Siamese engine we have already given a specimen in the plate of the steam frigate Retribution. Of this plan of engine we cannot approve, and we think Messrs. Maudslay would act wisely by giving it up in favour of some less precarious arrangement. The Siamese plan involves an increased leakage, increased friction, and increased radiation, while the grand purpose of direct action — saving of room — is only imperfectly fulfilled. Should either of the pistons leak steam, moreover, or either of the stuffing boxes leak air, a twist must be given to the parts of the engine, such as would arise if there were more pressure upon one half of the piston than on the other. Such a strain cannot, in our judgment, fail to be sooner or later injurious. The arrangement also involves the use of a low condenser, which the air-pump cannot thoroughly drain, and the pitching of the vessel, by causing the water to run from one end of the condenser to the other, sometimes causes the air-pump to make an ineffectual stroke, while at other times the air-pump is choked with water, which it can only with difficulty deliver, and fractures occur in consequence.

A part of the objections which we have here enumerated applies to the engines of Messrs. Forrester and Co., as made for the Helen Mac Gregor. We here transcribe an account of these engines from a modest and well written pamphlet, with which we have been furnished.

"The engine, of which the following is a description, is one of a pair lately constructed by Messrs. George Forrester and Co. for the Helen Mac Gregor, Hull and Hamburg steamer. The collective power of the engines is 220 horses', the tonnage of the boat being 573. The engines are of the form usually denominated 'direct action;' and without making any comparison between this and the various other forms of direct action engines hitherto made (some of them possessing much that is admirable in the ingenuity of their arrangement and the compactness of their different parts), I will endeavour plainly to describe the construction and principle of the above named engine, and to state wherein I conceive its advantages will be found, in practice, as suitable for sea-going steamers. The following short account will serve to explain the different working parts of the engine.

"The engine consists of two inverted cylinders, standing upon four strong wrought-iron columns, which rest on, and are secured to, the foundation-plate, and which, passing through suitable bosses, on the sides of the cylinders, support the entablature-plate and crank-pedestals above. The cylinders are placed 'athwart ships,' with their stuffing-boxes below them, and at sufficient height from the bottom of the vessel to allow of the main cross-bar, which connects together the two piston-rods, working the full length of its stroke below them: the stuffing-boxes are of double form, or, in other words, they have a space for packing both at top and bottom, being furnished with self-acting oil-cups for lubricating the rods. The power is transmitted directly, from the main cross-bar below to the cranks above the cylinders, by the connecting-rod. The two piston-rods and the connecting cross-bar are further secured, and made to work uniformly together, by means of a strong vibrating frame of cast-iron, forming part of the parallel motion, and which, with the side-levers, serves also to work the air-pump as well as the feed, bilge, and brine pumps.

"Each cylinder is furnished with a separate slide-valve, which two are connected together by a cross-bar common to both, being worked by the same eccentric motion. The object of thus dividing the valve is to shorten the lengths of the 'steam-ports,' the valves being brought much closer up to the face of their respective cylinders than would be the case if one only were used for both. The condenser is placed immediately underneath the slide-valve case, and the air-pump, foot, and discharge-valves, are similar in construction to those of the ordinary side-lever engines. The air-pump and condenser are connected together by a passage underneath the foundation-plate. The waste water is discharged from the hot well by an overflow-pipe through the side of the vessel.

"The application of two cylinders to one engine, having their piston-rods connected together, was first introduced by Messrs. Maudslay and Field, of London, for marine purposes, and is described in a patent taken out by them. The advantage of the use of two cylinders, instead of one of double the capacity, has been much questioned; and, independently considered, such an arrangement would only seem at first sight to involve a useless complexity of parts, but, when it is remembered that in using two cylinders there may be considerable advantage derived from the simplification of the remaining part of the engine, their introduction may be regarded as a very valuable addition to the various improvements which the steam-engine has from time to time undergone.

"Although it is hardly to be supposed that in engines of the largest class there will ever be required a cylinder of larger dimensions than is practicable to be constructed all in one, yet it has been found in practice that there is considerable difficulty in making cylinders of very large diameter as perfectly true as those of more moderate dimensions; and in regard to pistons, two of forty-eight or fifty inches diameter are stronger (upon the same weight), and less liable to accident than one of double the area. The use of two cylinders to one engine enables the manufacturer to undertake the construction of engines of double the power, without incurring an increased outlay for new tools, and greatly increases the facility for repairs at the government stations abroad, as there will rarely be an instance of a cylinder, or other casting of the double cylinder engine, too large to be constructed in a moderate-sized establishment.

"The cylinders have loose covers at each end, and from the upper ends the pistons are accessible without the intervention of the piston-rods, so that there is double space for examining and adjusting them without disturbing the lower covers, or disconnecting any of the working parts of the engine.

"The elevated position of the cylinders entirely obviates the danger sometimes arising from water running over into the cylinders from the boilers, as they are here at a higher level than the water line, and an accident from this cause cannot occur. The cylinders are also so much higher than the condensers, that they are kept perfectly free from water in this respect — an advantage well known to engineers who have the charge of marine engines.

"All the moving parts, as the piston-rods, cross-heads, &c. are below the water-line, and, being the most vulnerable parts of the engine, are thus entirely out of the reach of shot, as in the steam-frigate, whilst from the cylinders, which are decidedly the strongest parts of the engine, nothing is to be apprehended from this cause, as the construction of the engine is such that, if even the outer cylinder were disabled, the other one could be kept at work. There is no projection above deck except the ordinary crank-hatches; and the crank and paddle-shafts are precisely similar to those of the ordinary side-lever engine.

"The reduction of weight and space as compared with the ordinary engine is very great, and much additional room in the vessel is made available for cargo. The additional length of engine-room that would have been necessary if the ordinary beam-engines and common boilers had been used in the Helen Mac Gregor, in lieu of the improved engines and tubular boilers with which she is fitted, is 25 feet. Annexed are a few of the principal dimensions of the Helen Mac Gregor's engines, &c.: — Cylinders, 42 inches diameter; length of stroke, 4 feet 6 inches: air-pump, 33¼ inches diameter; length of stroke, 2 feet 4½ inches; capacity of condenser, including passage to air-pump, 44 cubic feet; capacity of hot well, 36 cubic feet; wheel, 23 feet 6 inches diameter to the outside of floats: number of revolutions, 23½: average pressure of steam in cylinder, 3¾ lbs."

We cannot say we can concur in all we have here extracted; the preservation of an engine from shot can scarcely, we conceive, be promoted by raising the cylinder above the water line; and whatever weight may be attached to the argument in favour of double cylinders, on account of their more manageable dimensions, is likely to be rendered unavailing by the application of direct action engines to the screw, which, on account of the increased speed of piston, will at once diminish the existing dimensions. There is no doubt a reduction of weight and space accomplished by the double cylinder engine; but the question is, whether an equal reduction is not accomplishable by engines which are not open to as weighty objections? In our humble judgment, the oscillating and double cross-head engines are both greatly preferable; and so we undertake to say it will be ruled by the supreme tribunal of public opinion.

The nature of the arrangement in the double cross-head engine will be made manifest by a reference to the engines of Messrs. Bury or Messrs. Fawcett. From the top of the piston-rod a cross-head and side-rods proceed, as in side-lever engines; and from the lower ends of these side-rods other side-rods ascend to a cross-head, situated above the other cross-head, and which, by means of a short arm, communicates with the crank. By this expedient, the benefit of a long connecting-rod is gained without the disadvantages incidental to the plans already mentioned. There is only one air-pump in Messrs. Bury's engine, but it is double-acting, so that, in effect, it is equal to two. A common objection to this description of pump is, that the air accumulates underneath the piston; but a provision is made to counteract this tendency, — the bulk of the air-pump piston being made to travel *past* the port, so as to expel air as well as water. We may here remark, that it appears expedient in this engine to avoid injecting from the bilge into the lower condenser, as coal-dust and other foreign matters might otherwise be drawn into the air-pump chamber, which would resist the descent of the piston, and probably occasion fracture.

In Messrs. Fawcett's engine there are two air-pumps, which are wrought by independent bell-cranks off a crank in the intermediate shaft. The inferior cross-head is made in the form of a cross, from the ends of which four rods proceed to cross bars working vertically in guides on each side of the cylinder. The effect of this arrangement is to bring the centres of the rods on each side of the cylinder into the same plane, whereby the twist incidental to an overhanging pin is avoided. Messrs. Fawcett have, we understand, since this design was made, more nearly approximated to Messrs. Bury's arrangement; and we believe their engines are likely to become a type which many will follow and many more approve.

The engines of the "Black Eagle" steam frigate, represented both in the plate of direct-action engines and in separate plates on a larger scale, have attracted much attention, as being the first specimen of oscillating engines applied to a large sea-going steamer. They do great credit to Messrs. Penn, both as regards the beauty of their workmanship and the efficacy of their performance, and after an adequate trial, their operation has been found so satisfactory as to have induced the Admiralty to order more engines of the same kind. The oscillating engine is now coming into universal favour for marine engines when fitted with paddle-wheels.

The structure and mode of action of the oscillating engine are so well understood, that a slight explanation will suffice to render the plates universally intelligible. The steam enters a belt on the cylinder, through the curved pipes adjacent to the ship's sides, as figured in Plate XIX., in which the vessel is sectioned transversely. From this belt it passes through the valve, by which means its distribution is regulated, and it escapes from the cylinder to the condenser, at the side of the belt opposite to that at which it entered. There are two air-pumps lying at an angle with the keel, as may be remarked in Plate XVIII.; and they are both wrought by a single crank in the intermediate shaft, the due position of the air-pump rods being maintained by means of guides. The slide-valves are provided with guides, and are wrought by means of an eccentric, in the usual manner; but the eccentric rod is not attached immediately to the valve lever, but to a curved transverse link, guided between the columns that support the shaft, and susceptible of a vertical motion. The curve of this link is designed to obviate the irregularity that would result otherwise from the combined movement of the cylinder and eccentric. The columns of the framing are of malleable iron; and a malleable iron cross is introduced at each side of the engine, to give the framing greater stiffness. The starting handles are so situated as to be accessible from a stage situated near the level of the cylinder covers; and this stage is continued round the engine, so as to afford easy access to all parts of it. There is nothing peculiar in the hot wells; they are bolted to the mouths of the air-pumps; and rise, as usual, to a high elevation. The paddle-wheels of the "Black Eagle" are of the feathering variety, something after the fashion of Morgan's, but greatly superior thereto in the details of their construction. These wheels have performed very satisfactorily, and are calculated, we think, to rescue feathering paddles from much of the discredit thrown upon them by the unskilfulness of former manufacturers. Though the oscillating engine now commands the suffrages of all the most competent authorities, it was for a long time regarded with but little favour; and it required all the authority of Messrs. Penn's name and success to gain for it a trial in sea-going vessels. One objection to its use was that the cylinder and stuffing-box would speedily become oval, on account of the pressure necessary to communicate motion to the cylinder. The existence of a tendency of this kind cannot be disputed; but it is so small in amount as to be imperceptible in practice; and although, after a lapse of years, it has been found that oscillating cylinders become slightly oval, yet the amount of ellipticity is, for the most part, actually less than is found to exist in the cylinders of common side-lever engines, after the same extent of trial. This, indeed, if the question be considered attentively, is by no means surprising; for the common parallel motion, if in the least degree out of adjustment, will exercise a most severe pressure upon the cylinder; whereas the maximum pressure that can be exerted on the oscillating plan is only that requisite to overcome the friction of the pivots on which the cylinder oscillates, and of which the amount is insignificant. Upon the stuffing-box, indeed, the tendency to wear oval may be more operative; but, to counteract this tendency, it is made of unusual depth, and a very substantial brass bush is fitted into its interior portion. The piston rod, moreover, is made of cast steel and of extra size. With these precautions, oscillating engines are found to work, for a number of years, without inconvenience from the causes mentioned.

Many nautical men, and some engineers, have objected to oscillating engines on account of the movement of the cylinder, which, they imagined, would become a formidable evil in the case of a vessel rolling heavily at sea. These objectors do not seem to have remarked that the rolling of the cylinder is neither dependent upon, nor proportionate to, the rolling of the ship, but is regulated exclusively by the movement of the piston; and it is difficult to see why a mass of matter, in the form of a cylinder, should be more formidable or intractable in its movements than a similar quantity of matter in the form of a side lever, or in any other shape whatever. It has also been objected against the oscillating engine, that the eduction passages are more tortuous than in common engines, so that the steam gets out of the cylinder less freely. We do not believe such to be the fact, if the comparison be made with the common run of marine engines; and in practice, no diminution of efficacy from this cause is appreciable. The fact is, all the objections that have been raised to the oscillating engine are merely hypothetical; they are anticipations of defects *to be* found out in large engines on the oscillating plan, and would probably be plausible enough to carry some weight, were it not the fact, that they have been completely controverted by experience. The remark, indeed, is heard sometimes even yet, that the oscillating method may do very well for small engines, but is of doubtful efficacy for large ones. But the definition of large engines has been continually changed, to escape the contradiction experience afforded, and that size is, in every case, decided to be large, which just exceeds the size of the oscillating engine last constructed. The grounds of this scepticism however, are now being fast contracted: and, indeed, experience has now demolished every objection that theory had raised. Some persons have apprehended that it would be difficult in large oscillating engines to obtain sufficient surface of trunnion to prevent the trunnions from heating; yet we have never been able to learn that any heating of those bearings has been found to occur in practice, and it appears probable that any such disposition would be resisted by the cooling effect of the steam passing through them, which, though hot, is of greatly inferior temperature to that of a hot bearing. It does not appear to us, however, that the trunnions may not be made with any amount of surface that is thought desirable, but we believe the proportion adopted by Messrs. Penn will be found adequate, and need not be increased.

ROTATORY ENGINES.

Rotatory engines are engines for obtaining a motion round an axis by the direct action of the steam, without involving the necessity of reciprocation. Some of them operate on the principle of reaction, of which the Æolopile and the engines of Avery and others may be taken as specimens; others operate on the principle of impulse, as exemplified by the wheels of Branca, Corde, and Pilbrow; a third kind trusts to the intervention of some liquid to produce the desired effect, as in the mercury engine of Watt and the wheel of Amonton; while in the fourth class the piston moves in a circle round the axis. It cannot be said that any one of the multitude of rotatory engines yet tried has been completely successful; nevertheless, we are by no means of opinion that a good rotatory engine will never be discovered, but, on the contrary, believe that the reciprocating engine will yet be superseded by a rotatory contrivance of a far simpler kind than any one now contemplates. Time will test the justice of this opinion. — It is, of course, impossible that we can give any enumeration, even, of the numberless schemes for rotatory engines that have at various times been projected, but we shall briefly describe a few of those which have attracted the most attention.

In Plate XX., entitled "Projects for Rotatory Steam Engines," *fig.* 1., is an engine with a revolving piston, contrived by Mr. Watt, who was the author of several plans of rotatory engines. One of these was the engine mentioned in page 16., as having been moved by the force of steam acting in a circular channel against a valve on the one side, and a column of mercury, or a heavy weight, on the other side; and the other engine was that mentioned in page 17., as having been of the form of a decanter. In *fig.* 1. E is the cylinder, A the revolving piston, B a valve opening and shutting like a door, H the steam passage, and K the eduction passage leading to the condenser. The steam pressing between B and A forces A into revolution, carrying with it the shaft D; and when the piston in its revolution meets B, it forces it back in a recess and passes by, when B is again immediately forced out by the pressure of the steam behind it. The defect of this engine is, that A strikes B very forcibly, so as materially to injure the machine. The leakage, moreover, is greater than in common engines. The plan has often been revived with new modifications, but has never realised a result equal to that reached by the reciprocating engine.

Fig. 2. and 3. is a representation of a rotatory engine, contrived by Mr. Murdoch. E E is a steam vessel, furnished with rollers A and B, toothed into one another, and the ends of the teeth are made steam tight, where they rub against the steam vessel. C and D are the axes of the rollers, *e e* and *f f* the ends of the steam vessel, H the steam pipe, K the eduction pipe, *r* the steam valve, Q the condenser, R the air pump, and Z a crank by which the air pump is wrought. The steam entering at H forces the toothed rollers round, in order to proceed towards the vacuum at K. There is much friction in this kind of engine, much leakage, and but a small power realised, in proportion to the size of the machine. The same scheme is proposed for raising water in Leupold's Theatrum Machinarum of 1720, where it is called the *Machina Pappenheimiana*, and, indeed, in these olden books devices are continually met with which have been re-introduced at a later time with great parade and pretension. There is a prodigious waste of ingenuity in this re-invention of things already invented before. The history of mechanical device has yet to be written; and there could be no task more useful than that of recording all known devices, so as to establish a point from which invention might properly begin.

Figs. 4, 5, 6, 7, and 8. represent a rotatory engine, contrived by Hornblower, and *fig.* 9. Carter's improvement upon it. The steam is admitted between two movable rectangular leaves, A and B, placed within a cylinder E E; and these leaves being so provided with catches that they cannot move back, the effect of the admission of steam between the leaves is to force the foremost of them into revolution. *e e*, *f f*, are the ends of the cylinder, *h* the steam pipe, *k* eduction pipe, D C the axes by which the steam is admitted and discharged; there are two steam valves *a*, and two exhaustion valves *b*, in the flat surfaces of A and B. The steam is admitted, and the exhaustion effected through the axes, which are made hollow for that purpose. M M, *fig.* 8., are clamps lodged in the circular channels *w w*, and their configuration is such that they will turn round easily enough in one direction, but when forced in the other will jam, so that they serve the purpose of ratchet wheels. Similar clamps are situated within the boxes *x x* and *y y*, *fig.* 6., and they are connected with the short double-ended levers *x y* and N N, affixed to the shafts. In *fig.* 9. M M are the clamps proposed by Carter, H H being the circular box as before, the ends of the lever N N, against which the clamps act, are eccentric to the box, so that they jam when N N moves in the direction of the arrows; *p p* are springs by which the clamps are carried round with the leaves. So soon as the moving piston comes round to the position occupied by the stationary piston, the stationary piston by a reversal of the valves moves on, and the moving piston becomes stationary, and so on continually.

Another rotatory engine, designed by Hornblower, is represented in *figs.* 183, 184, and 185., and consists of a steam vessel made of cast iron, of the form of a globe, flattened at the poles. *Fig.* 185. is a representation of the parts of the machine which move round within the steam vessel, and *fig.* 184. represents the interior of *fig.* 183., with its lid removed. The pipe A, *fig.* 183., receives the steam from the boiler, to which is connected a valve-box, of any usual construction, by which to regulate the admission of steam. At B the eduction pipe is connected, leading from the upper apartment to the condensing apparatus, and turning in such a direction as may be most convenient for the discharging pump to be wrought by the axle of the engine. D D is a middle part of the steam vessel, furnished with flanges for the purpose of screwing it to E E, and also for receiving the lid; by which means the partition within is secured to its place in the middle of the machine; and the lid may easily be removed for the purpose of rectifying and repairing the internal structure. G is the square part of one end of the axis of the machine, over which is placed a gland H, divided into parts, in order that it may be put on over the square, and properly embrace the round part of the axis. Within this gland is a stuffing-box, for the purpose of keeping the axle both air and steam tight. In one side of the lower apartment of the steam vessel is a small opening, secured by a lid, for the purpose of cleaning that part of the machine.

Fig. 184. represents the partition within the steam vessel, which may be made either of brass or iron, or of both those metals combined. B B is the lower flange, the upper part being taken away. C C are the two openings or passages for the vanes: these the inventor calls vane-ports; and to reach a right conception of their figure, it may be explained, that the largest vane-port is formed by the exterior portions of two cones, and by a portion of the concave part of a sphere. The extent of this passage throughout must at least be equal to ninety degrees of a circle, and the vanes must be of a sufficient width for two of them always to make their entrance into the vane-ports before the other two make their exit. The edge may, therefore, be supposed to descend into the lower apartment one half of its depth, and to rise the other half to meet the eye. The part E is formed spherically, and is provided with a packing-groove, which meets the edge of metal in the middle of the vanes. F F is the main axle of the machine, as well as the descending vane, by which means both the nave and the vanes move steam-tight in their revolutions. V V V V is that part of the partition which forms a plane at the axis of the globe, and is

Fig. 183.

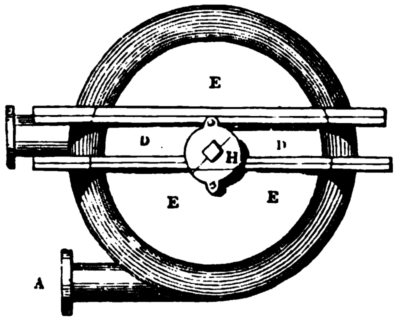


Fig. 184.

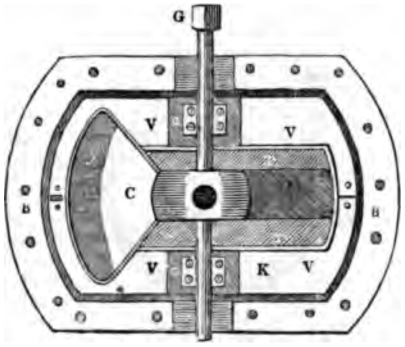
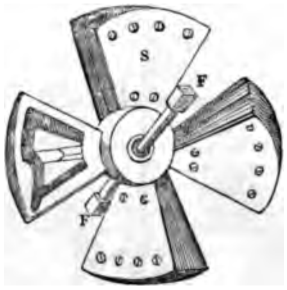


Fig. 185.



HORNBLOWER'S SECOND ROTATORY, 1807.

secured in its place by being seated in a rabbet with the usual jointing materials on the interior margin of the steam vessel. Two brasses, G G, are let down into the partition, and they are raised or depressed by screws, as occasion may require. The open vane exhibits a frame of metal, which receives a plate on each side: these plates, with the edge of metal, K, cast with the frame, form grooves and vacuities to receive the packing.

Mr. Samuel Clegg's patent for a rotatory engine is represented in *figs.* 186, 187, and 188.

Fig. 186. is the under side of a circular piece of cast-iron, and of a diameter and thickness proportioned to the size of the engine. I is the common centre of the different circles shown on this piece. With any convenient radius less than that of A A, describe the circle C C, and within the latter the circles D D and E E, the radius of the latter being the least of those now named. From the uses of these parts, which will be immediately described, an idea of their relative dimensions will readily be inferred. Let that part of the surface A B, A B which is contained between the circles A and C, be plain. Between the circles C and D sink a circular groove C D of any given depth; and between the circles D and E let another circular groove be cut, of the breadth D E, and of any given depth less than that of the groove C D. Let the remaining part of the surface A B, namely, that included between E and B, be cut down to any depth less than the depth of the groove D E. Into the groove C D let such a number of segments of a circle be fitted as shall form a complete circle, excepting the space at L, which is occupied by adjusting screws or springs, to keep the segments close together. The segments are the breadth (or nearly) of the groove C D, and of a depth less than that of the groove C D. Those sides of them which apply to each other are to be ground together plain, and air-tight if possible. Their under-surfaces, which are shown in *fig.* 186., are to be flat, so that the whole may form one complete plain surface, excepting the space before mentioned, which is taken up by adjusting screws or springs L, which screws or springs are placed so far below the surface as to let a roller pass by them, which will be mentioned hereafter.

Fig. 187. represents a vertical section of the plate and grooves of *fig.* 186., resting upon a circular chamber or hollow space, Y Y, to which chamber the said plate forms a light covering, excepting that space occupied by springs or screws, L L, as before mentioned. I, the centre of all the grooves and circles before described, is also the centre of the shaft. On the shaft I is fastened a plate or coupling Z, in which is inserted a bar, F. This bar may be of any given breadth, but in depth must be less than that to which the circle E B was cut below the surface A B. To this bar is attached a wheel or roller, G, shown in *fig.* 188. The manner in which it is attached to the bar F is also there seen, and it is so attached to it that the top of the wheel or roller, G shall always be higher than the top of the bar F. The wheel G, being attached to the bar F, will, when the bar is made to revolve, describe a circular path H H H, along the plain surface of the segments before described. *c*, is the condenser, *a* the air-pump, *b* the air-pump bucket, *d*

Fig. 186.

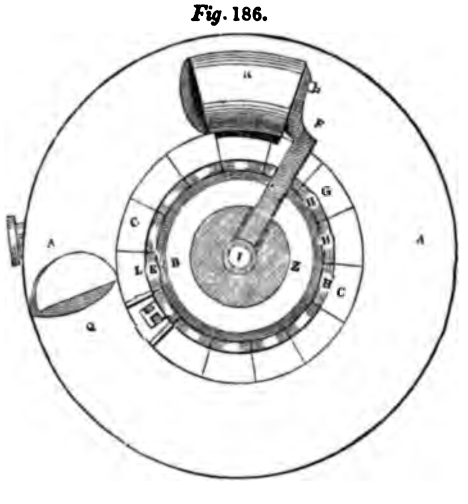


Fig. 187

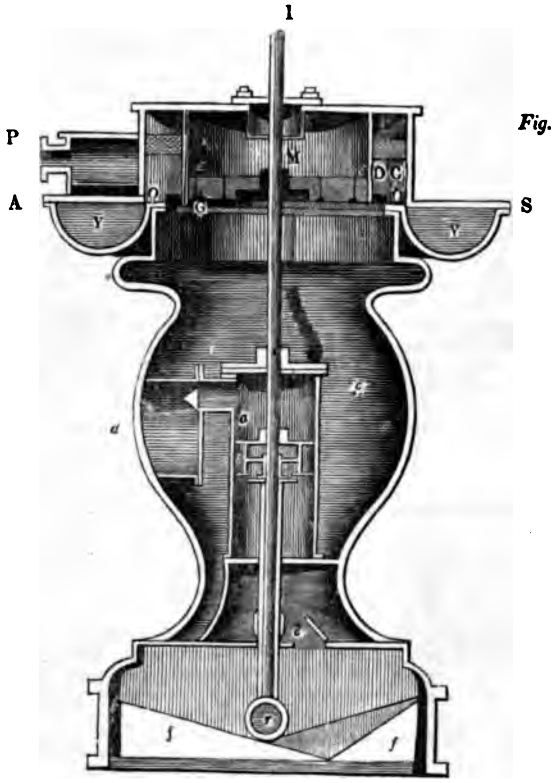
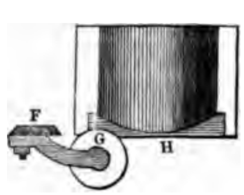


Fig. 188.



CLEGG, 1809.

the hot well, *e* the foot-valve, *ff* the cam which works the air-pump, and *r* a roller resting thereupon. Let that portion of the plain surface of each segment, which answers to the path of the roller G, be rounded off in such a manner as to make that portion of the surface an arc of a circle, the convex circumference of which is presented to the roller G. In *fig.* 188., at H, is shown a perpendicular view of one of the segments, rounded off in the manner described, and presenting its convex circumference to the roller G. There may, likewise, be another roller attached to the bar behind it, to lower down the segments in the same manner in which they are raised by the first roller. Now it is obvious, all the said segments being in their places in the groove C D, *fig.* 186., that the roller G, in performing a revolution round the centre I, must travel along a series of convex arcs of circles equal in number to the number of segments in the groove C D. The groove D E is, in fact, a recess in the deeper groove C D, and may, if necessary, be filled with hemp or tallow, or any other material, which may answer the purpose intended. It must be remembered that *fig.* 186. is a view of the under side of the machinery. *Fig.* 187. is a section of it, supposed to be in its proper position, resting as a cover to the circular chamber Y Y, and the segments resting upon a flat facing O O. Each segment projects over the facing O O on both sides; their projection on one side completes the cover over the hollow chamber, and the other is the rounded surface for the roller to lift them. The facing O O is exactly, or as nearly as can be, level with the under side of the plate A B A B, when the plate is on its place, as represented in *fig.* 187.; so that, when the segments are all in their places, they complete the semicircular chamber, and fit so close on their seats and in the groove, that were the chamber to be filled with any elastic fluid, they would prevent its escape, or nearly, excepting where the space is left for the springs or adjusting screws. The use of these segments, *which are what the patentee claims as his invention*, is as follows:—Conceive a door or valve to be fitted in the hollow chamber at Q, and a piston, R, likewise fitted in the chamber so as to move round in it, and the bar F made fast to the piston, on the side and in the manner represented in *fig.* 186.; then, if an elastic fluid of sufficient strength enters the chamber at N, it will press equally against the door-valve and the piston; but the door or valve being immovable, and the piston movable, the piston will be propelled forward in the circular chamber by the elastic fluid. The bar F being fastened to the piston, and the roller G to the bar F, in the manner represented in *fig.* 188.; and the roller being in motion with the bar and piston, the roller will lift the segments in succession as it comes in contact with them. The segments before the bar, being by this means lifted, allow the bar to pass; and the operation being the same in all, the bar and piston make a complete revolution. Each segment, as soon as the bar leaves it, falls down by its own gravity, or by springs, or any other contrivance, so that the opening which is made for the bar to pass is closed before the elastic fluid reaches it; the elastic fluid being kept from the opening by the inner breadth of the piston exceeding the outer diameter of each segment. The door or valve is lifted out of the way of the piston, when the piston comes in contact with it, into the opening in the plate at N, a recess being made in that segment which is opposite the door for that purpose; during which time the elastic fluid is shut out, but it enters again when the door returns to its seat, and thus the operation continues. There is much ingenuity in this contrivance: the principle on which the bar is enabled to pass the segments is nearly identical with that introduced by Mr. Clegg into the atmospheric railway, for enabling the piston within the pipe to be joined on to the carriages outside.

Our next example is Mr. Turner's rotatory engine, patented in 1816. *Fig.* 189. is a plan of the engine, represented so as to show the internal structure. *Fig.* 190. is another plan. *Figs.* 191. and 192. are sections, taken through the axis of the engine in different directions. A A, B B, C C, is the cylinder, or external case of the engine, made in two or more parts, which are fastened together with screws, so as to form a circular or annular passage, the transverse section of which is likewise circular, as shown at E E, *figs.* 191. and 192. The piston F, *fig.* 189., is accurately fitted into this circular passage, and is caused to revolve therein by the pressure of the steam, which is applied behind it, or on the side F, whilst a vacuum is made before it, or on the side G. The piston being connected with a central plate G, which is fixed fast upon the axis or shaft H, the said shaft is put in motion; and by wheel-work I, or any machinery which is best adapted, the power of the engine is communicated to any useful purposes to which it is intended to be applied. The means by which the force of steam is made to produce the rotatory motion is as follows:—Two valves or sliders, K and L, are applied at the opposite sides of the annular passage or cylinder E E, in the manner represented in *figs.* 189. and 191. The edge of the central plate G, which has the projecting arm to communicate with the piston, must be made so that they can be made to shut up the passage of the cylinder E E, as represented at L, and prevent the passage of the steam through the same, or the slider may be opened, as shown by the dotted lines, to allow the piston F to pass freely through the cylinder. This is done by moving it sideways on its centre 3. out of the cylinder, into the box or case M, which is provided for its reception. The sliders are put in motion by a communication from the outside of the engine, so that each one shall begin to open as soon as the piston F approaches it, and shall be completely opened whilst the piston passes by, and that it shall then descend again upon its seat. N O, *figs.* 189. and 192., are two passages, through each of which the steam is alternately introduced and withdrawn from the cylinder. The two passages are placed

Fig. 189.

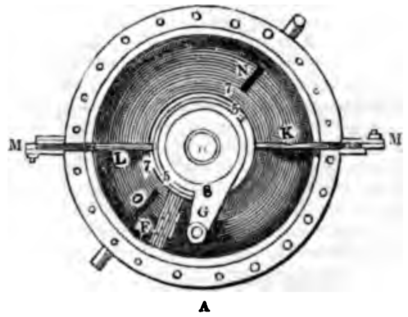


Fig. 190.

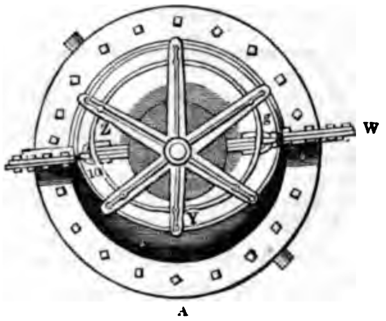


Fig. 191.

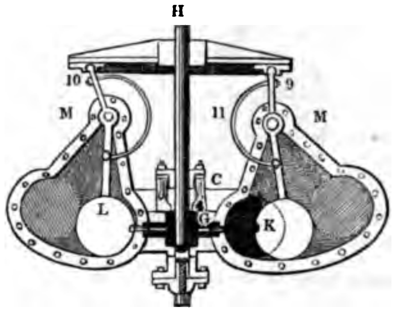
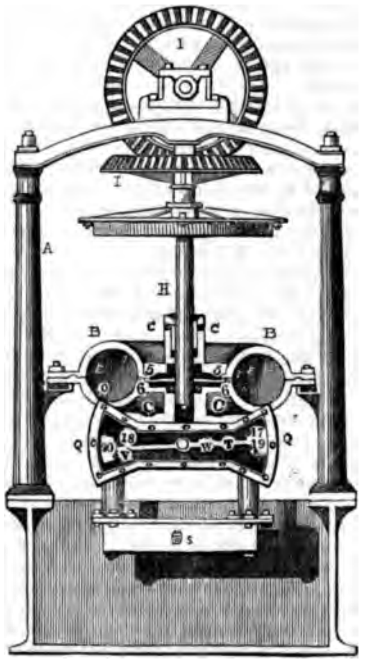


Fig. 192.

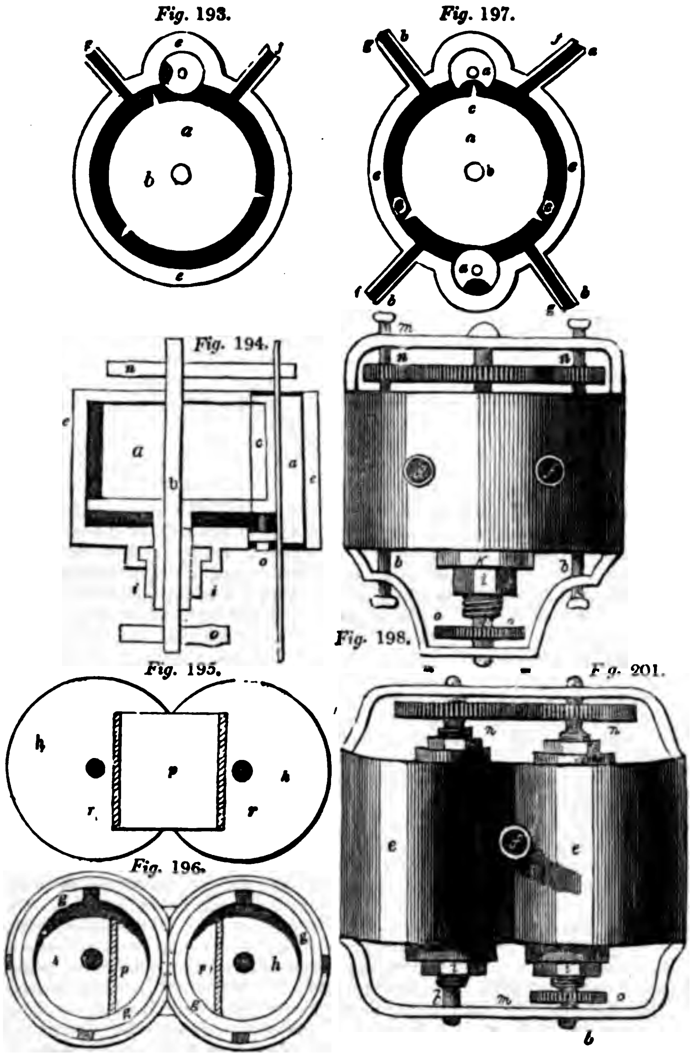


TURNER, 1816.

on opposite sides of the centre of the engine, and are provided with valves or cocks, which are adapted to be opened and shut by the action of the machinery in such succession, that when steam is entering from the boiler into the cylinder at one passage, it shall be going out into the open air, or to the condenser, at the opposite passage. The mechanism which actuates the slides K L, and the mechanism which opens the valves for the admission and exhaustion of the steam through the passages N and O, act in concert with each other, and in unison with the motion of the piston F; so that, as soon as possible after the piston has passed by the seat of a slider, the slider shall be lowered down into its place ready to close the passage of the cylinder behind the piston. The instant the piston has passed by the next opening, the steam is admitted to flow through it, and act between the slider and the piston, to force the piston forwards in the cylinder by its expansive force.

To explain the action of the engine more clearly, suppose the parts in the position in *fig.* 189.; the slider L is shut, and the steam is flowing, through the passage O, into the space between the slider L and the piston F; at the same time the passage N is open to the condenser, to exhaust the steam from the remaining part of the cylinder, and to remove the pressure from the front side G, of the piston. In consequence, the pressure of the steam acting behind the piston F, puts it in motion in the direction of the arrow, and drives the arm of the central plate before it. The slider K, is now in the act of opening, and by the time the projecting part of the plate G arrives at its seat, it will be quite open into the box M, where it will remain until the piston F has passed by its seat; it then begins to descend, and by the time the piston arrives at the opening of the passage N, the slider K will be completely shut and stop the cylinder. The instant the piston has passed over the opening of the passage N, the steam valves are changed by the machinery, so as to admit the steam into the passage N, and also to allow the steam to pass away, through the other passage O, to the condenser; in consequence, the steam enters the space between N and K, and thus, being behind the piston, drives it still forwards towards the slider L, which immediately begins to rise by the action of the machinery, and as soon as the projecting part G of the central plate approaches it, it will have retreated into the box M, leaving the cylinder free for the passage of the piston. Immediately after the piston has passed, the slider L descends again, and gets settled to its place by the time the piston arrives at the opening O; and the instant the piston has passed over this opening, the steam valves are changed again; so that the steam will be admitted at O, behind the piston, and act between the slider L and the back of the piston, to force it forwards, which is the same position represented in the figure. By this means the pressure of the steam is always made to act behind the piston, and the vacuum is maintained before it. The sliders K and L are put in motion by levers 9 and 10, which are fitted on the outsides of the boxes M, but move upon the same centre pins 3, as the sliders move upon withinside the boxes, the levers being forked, as shown in the figure, to reach on each side of the boxes; and the centre pins 3 pass through the sides of the boxes, and also through both forks of the levers 9, 10, but do not turn round in the holes. To communicate motion from the levers at the outsides of the boxes to the valves withinside, curved rods, 11, 11, are carried from the levers through the sides of the boxes M, and jointed to the arm of the sliders; stuffing boxes are formed round the rods to make tight fittings where they pass through the sides of the boxes M. The ends of the levers, 9, 10, are made to be included in an eccentric groove or rein, Z Y, fixed to the central axis H. The form of this is shown in *fig.* 190., and is such as to hold the sliders shut, except during the time that it is necessary to lift up the same to allow the piston to pass by. To make the sliders fit steam-tight when they are shut, they are made rather larger than the diameter of the cylinder, and are received in grooves made round in the inside, and the valves are ground against one of the faces of each of these grooves, so that they will fit tight without any packing. The piston is made of several segments put together, with springs behind them, to throw them out against the inside surface of the cylinder, and it is thus made tight without any packing of hemp.

We now come to the patent of Mr. Joseph Eve, taken out in 1825. *Fig.* 193. presents an end section; *fig.* 194. a longitudinal section of this engine. "*a a* are the cylinder and cone, revolving in contact in opposite directions, the cone having one groove, and being one third of the diameter of the cylinder, which latter has three wings or pistons *c c c*, the ends of which, as they revolve, touch the outer case *e*, and do not admit any steam to pass The steam is admitted through the pipe *f*, and acting on the wing *c*, causes the cylinder to revolve until the said wing passes the pipe *g*, when the volume of steam lodged between each two wings, is allowed to escape. The wing, which has thus passed, falls into the groove *d* of the cone, the bottom of which groove it touches in passing, thus allowing no steam to escape between. The said wing *c* then passes again by the steam pipe *f*, and is acted upon as before described, and so on in rotation. The cylinder *a*, which is firmly fixed to its axis *b*, rests on one side on the outer case *e*, through which the axis projects; but as there is some friction produced by the revolution of the cylinder at its two ends touching the outer case, a false end *h h*, is placed under the opposite end of the cylinder, which false end slides on the axis *b* freely, and has a thread cut at the end, by means of which, and the adjusting nut *i*, the cylinder, if worn at the two ends, can be easily tightened and adjusted. The adjusting nut is confined by the collar *k*, which collar is screwed to the outer case. The conical shape of the small runner, which can likewise be moved upwards or downwards in the outer case, serves to keep the two convex surfaces of the cylinder and cone in contact. The groove *d*, in the conical runner, is cut into a separate piece of metal, which slides by an adjusting screw *o*, up and down: so that when the engine is adjusted, the groove *d*, on the piece of metal, into which the said groove is cut, can be moved up and down, so as to fit the wings of the cylinder. Letters *n n*, in *fig.* 194., represent two cog wheels running into each other, attached on the outside of the engine to the axis of the cylinder and cone, placed there for the purpose of producing a corresponding revolution of the said cylinder and cone, thus causing the groove of the cone to present itself regularly to the wings of the cylinder; *o*, is a pinion fixed to the other end of the axis, by means of which any machinery can be put into motion.



EVE, 1825.

Another variety of steam engine on this principle is shown by an end section view in *fig.* 197., and an external view in *fig.* 198. This engine has a cylinder with two small conical runners on each side, the said conical runners being of the same construction as before described, with one groove cut into each, and being one third of the diameter of the cylinder. There are two induction and two eduction steam pipes; and although the engine may be, with the exception of the addition of one of the conical runners, exactly of the same size as the one first described, a double quantity of steam is requisite, and twice the power of the former engine is gained: the steam enters through the pipe *f a*, and acts on the wing *c*, which, after having passed the pipe *g o*, where the steam escapes, falls into the groove *d*, of the lower cone, and appearing at the induction steam pipe *f b*, is loaded again with steam pressure, which it discharges at the second eduction pipe *g o*, and then enters the groove of the upper cone, which having passed, it is loaded again at the first-mentioned induction pipe. Letters *m m*, are bridges, by which the spindles or axes *b b b*, are supported. This engine has three cogwheels *n n n*, attached to the three spindles, so as to cause

Fig. 199.

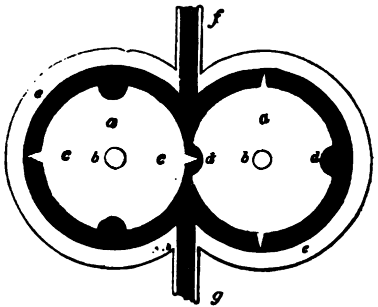
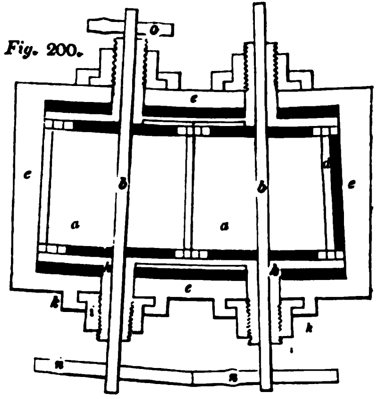


Fig. 200.



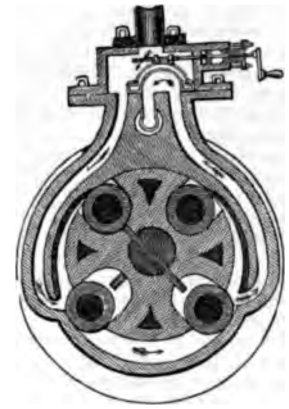
EVE, 1825.

the cylinder and cones to revolve in unison, and, like the first-described engine, has a pinion *o*, on the opposite end of the axis of the cylinder. *Fig.* 199. shows an end section, *fig.* 200. a longitudinal section, and *fig.* 201. the exterior of another form of this engine, in which there are two rollers. The conical runners, in this case, are of an equal length and diameter, each has two wings or pistons attached, and two grooves cut into it, and in revolving in opposite directions, the wing of one runner falls alternately into the groove of the other. The steam enters by pipe *f*, and as the cylinders are running in contact, it cannot escape between them, but acts upon the two wings in opposite directions, and escapes at the eduction pipe *g*, after the said wings have passed the same. By reference to *fig.* 200., which represents a longitudinal section, it will be seen that the two cones have each two false ends *h h*, sliding freely on their spindles; the two outer cases *e e*, fit over the runners and their wings exactly; each of the four false ends has an adjusting nut, by which the engine is tightened if steam should escape, or slackened if it should run too tight. Each pair of the false ends, where they join, have a plate that connects them and breaks their joints, so as to prevent an escape of steam; this plate *h*, slides into the groove *r*, cut out of the false ends, as exhibited by *fig.* 195. and *fig.* 196., the former showing an end view of the false ends with the connecting plate in the middle. On these false ends packing rings, *g g g*, which are confined to the sliding plate, as exhibited in the latter figure, are placed. These rings press against the hollow outer cases, and prevent any steam escaping by them. These packing rings are shown in section, in *fig.* 200. It will be evident that the false ends need not be made true, if the connecting plates and packing rings, as above described, be adopted, and that the engine, if provided with moveable false ends, conical runners, and the afore-described connecting plates, and packing rings attached, as shown in *fig.* 200., can always be kept steam-tight, and by use the various parts, on which there is any friction, will fit better."

Fig. 202. is Beale's rotatory engine, in which the steam is admitted on the one side of an eccentric frame, armed with rollers, which serve the place of pistons; and the centrifugal force is reckoned capable of keeping the rollers against the interior of the cylinder. An engine upon this plan has been put into a steam vessel, but its success has not been such as to induce its more extended adoption.

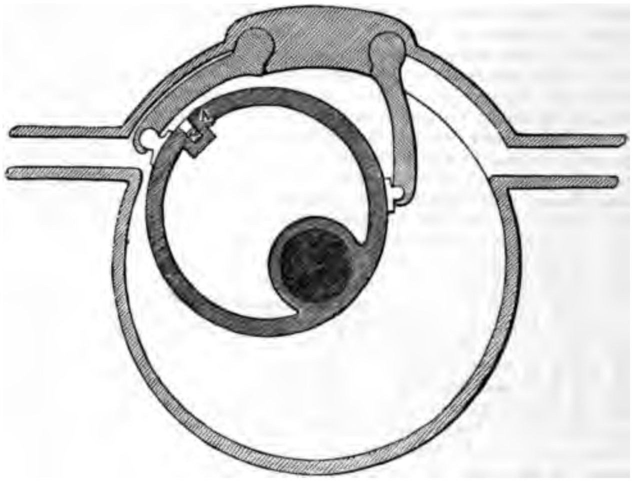
Fig. 203. is the engine specified in the last patent of the Earl of Dundonald, and which has been introduced in the steam frigate "Janus." It is not very correctly represented in the accompanying sketch, which is copied from the rough drawing given in his specification. This plan very much resembles that contrived by Watt, except that an eccentric is substituted for a leaf, and a ball and socket joint is introduced in order to enable the steam and exhaustion doors to make a steam-tight junction with the eccentric. This contrivance has not as yet realised any great success, and the prevailing opinion among engineers appears to be, that it will not supersede ordinary engines. Similar engines have been tried on many

Fig 202.



BEALE.

Fig. 203.



THE EARL OF DUNDONALD, 1844.

former occasions, but they have been always found to involve either a ruinous amount of leakage, or such a degree of friction as to make the plan impossible in practice. These difficulties will probably be abated as the resources of workmanship increase; but they exist at the present time, and have proved fatal to nearly the whole tribe of rotatory engines.

The following is the description of Mr. Peter Borrie's rotatory engine, represented in one of the engravings. The letters in all the figures refer to similar parts. *Fig.* 1. is a transverse section, through the centre of the cylinder; *fig.* 2. a longitudinal section of the engine; *fig.* 3. a transverse section through the centre of the air pump, and showing an end elevation of the other parts; *fig.* 4. a side elevation of the engine; and *fig.* 5. a ground plan. A is the foundation plate, to which all the parts of the engine are directly or indirectly attached. B is the external cylinder, fixed to the foundation plate. C is a smaller cylinder, revolving within the external one, on a shaft D, whose centre is placed so far above that of the external cylinder, that their circumferences may touch one another at the upper point h^1. Thus the space between them gradually increases from h^1 to the lower point h^2. The shaft D passes through steam-tight stuffing boxes in the cylinder ends, and revolves in bearings on the frames Z Z, which are firmly bolted to the foundation plate, and stayed to the cylinder. E E are two sliding pistons, consisting each of two arms, connected together by four rods passing over the shaft: their breadth is equal to that of the outer cylinder, and their joint length over their extremities is necessarily somewhat less than its diameter, owing to the eccentricity of the revolving cylinder: these pistons slide freely at right angles to one another, through passages made in the circumference of the revolving cylinder, their sliding motion being caused by the pressure of one of their extremities on the ascending side of the outer cylinder, (whichever side that may be,) and the eccentricity of the revolving cylinder through which they slide. As their length is always slightly varying during the course of a revolution, the difference is made up by metallic packing, placed between the two thicknesses of plates of which the arms of the pistons are composed: the packing is pressed by springs toward the sides and circumference of the outer cylinder, and will be understood by referring to *figs.* 1 and 2. on the drawing. There are metallic packings in the passages in the inner cylinder through which the pistons slide, which are pressed on the flat surfaces of the pistons by springs, and prevent the steam passing to the interior. There are also two steel rollers at the inside of the packings, which are pressed up to the flat sides of the pistons by screws; these are for the purpose of diminishing the friction of their sliding motion. These rollers would not be necessary excepting in large engines. The rim of the inner cylinder is made to project into metallic packing boxes in the cylinder ends; thus the steam is entirely prevented from passing into the interior of the inner cylinder; a packing box is also placed at the point of contact h^1, to prevent the steam passing to either side. It will therefore be understood, that the steam only acts on the projecting part of the sliding pistons, between the inner and outer cylinders. The steam in coming from the boiler, through the steam pipe F, has first to pass the slide G, which is worked by the handle H; it is used for regulating the speed of the engine, and also for stopping it, when required. After passing the above slide, it enters the steam-tight jacket J, the bottom of which is the slide face having the four cylinder ports, K, L, M, and N, and the eduction port Q on it. A slide O worked by a handle P passes over these ports for the purpose of reversing the motion of the engine. There are two ports O^1 and O^2 on the slide, one of which, O^2 in the position the slide is shown on the drawing, is open to the steam port L, the port N is closed, and the two ports M and K are open to the eduction port Q, so that when the slide is in this position, the engine will necessarily move in the direction indicated by the arrows, and by moving the slide along until the port O^1 is above the steam port K, then will the port M be closed, and N and L open to eduction, so that the steam will act at the opposite side of the cylinder, and consequently the motion be reversed. The lower cylinder ports M and N are *never* used for admitting steam, but only for leading off the eduction; the object in placing them so low in the cylinder is to allow the vacuum to act upon the pistons sooner. From the relative position of the two cylinders, the distance between their circumferences gradually increasing from contact at the upper point h^1, to the greatest distance at the lower point h^2 (which in this case is one sixth of the diameter of the external cylinder, but may be varied according to circumstances), it will be seen that in whatever direction the engine revolves, the area of that part of the pistons which is acted on by steam and vacuum gradually increases, so that the principle of expansion is carried out, without the use of expansion gear. The steam passing through the eduction passage Q is conducted by the eduction pipe R to the condenser S. T, is the injection slide, placed at the lower end of the eduction pipe, and conducting the water up the pipe, so as to act fully on the steam in passing downwards: it is worked by a lever and rod connected to the handle U, which is placed in proximity with the other starting handles H and P. V, is the blow through valve. W is the air pump, which is a double-acting one, the interior arrangement of its valve, &c. is shown at *fig.* 3; it has a metallic packing piston, which is worked from the main shaft by a crank and connecting rod, and the piston rod is kept parallel by two slide guides bolted on the air pump cover. X is the hot well, and Y the discharge passage. The pumps are worked from the main shaft by an eccentric C, connected by rod and lever to a rocking shaft *d*, on which are keyed two levers *e* and *f*, which are connected by rods to the pumps *g* and *h*; the pump *g* is intended for the bilge water (supposing this to be a marine engine), and the pump *h* for feeding the boilers; the latter has its valve chest *j*, bolted on the hot well.

The drawing represents an engine with outside cylinder, 3 ft 6 in. diameter, and 1 ft. 6 in. long; and internal cylinder, 2 ft. 11 in. diameter. The steam is supposed to be at 30 lbs. pressure above the atmosphere, and the vacuum in the condenser to be 12 lbs. per square inch. From these data, the projector calculates that, at a speed of 50 revolutions per minute, allowing 10 per cent for friction, the engine will raise 1,976,400 lbs., 1 foot high per minute, with a consumption of ·36 cubic feet of water, in the shape of steam. We do not altogether understand the very long calculation by which Mr. Borrie arrives at this result; but, from somewhat simpler computations of our own, we believe he is not far wrong in his computation, which makes this engine one of about 60 horse power. As it is admitted, that a common low pressure condensing Boulton and Watt engine requires about three times the quantity of steam for the same power, the patentee arrives at the conclusion that his engine will save two thirds of the coals consumed by the ordinary engines. Several considerations prevent us acquiescing in this. In estimating the quantity of steam used in a Boulton and Watt engine, 37 per cent. is allowed for friction, leakage, &c., besides one twelfth more for filling the passages, slide valves, &c. In Mr. Borrie's estimate of the powers of his own engine, he allows only 10 per cent. for friction, and nothing at all for steam wasted in filling passages. Then, again, there can be no fair comparison between a high pressure condensing and expansive engine, with steam at 30 lbs. on the inch, and expanding to above twice its original volume, and a low pressure non-expansive engine.

Mr. Joseph Wood's patent rotatory engine, which is figured in one of the plates, consists of the following principal parts: — the revolving parts consist of an axle passing through a circular disc plate and ball, which plate and ball are termed the diaphragm of the engine. These are firmly fixed on the main driving shaft at right angles to its axis of motion. The disc plate, and consequently the axle, has also attached to it a piston oscillating towards each end, in a line with the main axle, and passing through a slot-hole formed in the diaphragm from its centre to its circumference. This diaphragm or disc plate is furnished with a channel or way, passing downwards from each side of the slot cut through it for the piston to pass, and this way or channel extends through the ball, where one way or channel turns to the right and the other to the left, and emerging from the said ball, continues as a channel formed on the axle to the admission and exhaustion chambers respectively.

The stationary parts in this modification of the engine consist of two conical surfaces or side-pieces, inclosed in a spherical case in such a manner that one portion of each side of each cone shall be perpendicular to the axle of the machine, and in contact with the revolving diaphragm on its opposite sides, and also on the opposite sides of the axle; and, moreover, where the portion of one side of the diaphragm is in contact with one cone, it has the opposite cone at its greatest distance. The apex of each cone is, however, removed and cupped so as to fit the centre ball of the diaphragm before mentioned; and that part of each cone in contact with the diaphragm and its ball is consequently subject to wear by friction, and is made of a separate piece of suitable metallic packing, and adjusted by springs or other mechanical means.

In this modification of the machine the spherical case continues all round the cones (excepting where it is pierced for the axle to pass through), and the cones are hollowed out to form chambers for the admission and dispersion of the steam or other fluid, the direction of which is altered by a valve for reversing the induction and eduction apertures.

The cones being placed as described, within the spherical case, a space is left between them, which is divided into two equal parts by the diaphragm before mentioned, the diaphragm being in light contact with the spherical case throughout its periphery, and at one point of each cone and its central cup; and each independent space between the diaphragm and the cones will present the form of a double wedge, jointed at the base, at that part where the cones are furthest from the diaphragm. If the actuating fluid were introduced into one half of the space, it would tend to press the diaphragm into the opposite one, and to make this power available, a piston is introduced of the form or section of the entire space, at right angles to the diaphragm, which piston oscillates from the centre of the axle, through the slot or opening in the diaphragm before mentioned, so as to slide over the sides of each cone as the space on either side of the piston increases or decreases. Further, the actuating fluid is conveyed through the axle and diaphragm by the pipe or channel before mentioned, and impinges immediately on the piston (except when used expansively) throughout the entire revolution of the piston, diaphragm, and axle, all of which move simultaneously. Just before the piston passes the culminating line of contact of the diaphragm and cone, the exhausted fluid is liberated and passes through the slot-hole and second or exhaust passage of the diaphragm into a condenser or otherwise, whereby one side of the piston is constantly exposed to pressure, and its opposite side to the vacuum or atmosphere.

Fig. 1. is a longitudinal section of the machine, taken vertically, the piston being removed. *Fig.* 2. is a transverse vertical section, taken through the centre of the machine, the diaphragm and piston being removed. *Fig.* 3. is another longitudinal vertical section, showing the cones in plan, or as they would appear in the engine; and the diaphragm and piston, in the situation they would be in after making a quarter of a revolution, from the situation shown in *fig.* 1. *Fig.* 4. is a detached plan view of the diaphragm and section of axle and part of the piston. *Figs.* 5, 6, and 7. are partial views, showing the details of the piston, and its attachment to the axle and diaphragm. *Fig.* 8. is an end elevation of the engine. *Fig.* 9. is a front elevation of the same. The letters refer to the same parts in each figure. B is the main axle of the machine, and on it is firmly fixed the diaphragm and ball A; and within the diaphragm, through the ball, and on the surface of the axle. are the steam passages *a a*, commencing at the slot; C is the body of the piston, and is keyed into the small shaft N, passing through the centre of the axle and diaphragm, which small shaft is adjusted and mounted by means of screws at the ends, so as to permit a partial revolution on its axis. This small shaft or pin conveys the pressure immediately from the piston to the axle B, and is extended as far as possible, to increase the base and insure steadiness of action. The piston consists of its body part C, which incloses a packing piece O, pressed up against the spherical case E, by a spring, and carrying on each of its sides a rounded part, on which P, the side packing of the piston, swivels to adapt its rubbing surface to the inclined planes of the cones D D, as shown in *fig.* 3., and these packings are kept tight by the same spring as that which elevates the packing O, this effect being consequent on the shape of the packing piece O. The tail-pieces shown at O^1 (*fig.* 6.) are the parts of the packing in contact with the cups of the cones; *pp* are two pieces for packing between the bottom of the piston and the sides of a hole in the axle in which it oscillates.

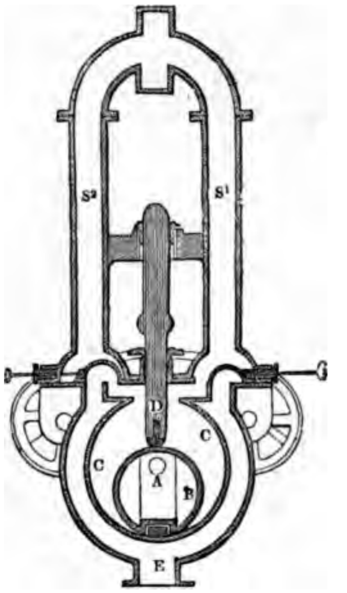
In *fig.* 5. the amount of liberty or space allowed for the oscillation of the piston is shown. The periphery of the diaphragm is rendered tight by two rings of metal L L (*fig.* 1.), formed with an inclination on the sides which are in contact with the diaphragm, and vertical on the others, which are in contact with the channel in the spherical case E; and these are pressed into contact with both surfaces by a coiled spring, or other mechanical means. M M are rollers moving with the diaphragm, to assist in steadying its motion and equilibrium, and are kept apart by distance pieces *m*, *m*, *m*, which may be dispensed with, if desired.

The cones are lettered D, and the packing of the culminating lines, and also of the cupped cavity, are shown at K, and are pressed forward against the diaphragm by springs *k*, or other mechanical means.

E is the spherical case, constructed in this instance in two pieces, and joined together by means of flanges, bolts, and nuts; and has a channel cut out for the periphery of the diaphragm and its packing L to revolve in; and also to contain the rollers M M, as before mentioned. *e* is a part of this case, and contains the stuffing boxes R R, to prevent the escape of steam from around the axle.

F F are the admission or exhaust chambers before mentioned, contained between the back of the cones D and the case E; and a pipe or passage *f f* proceeds from each of these to a common slide-valve G; and when the action of the engine is required to be reversed, the valve is moved by a handle, so as to direct the current entering from the pipe H to either side of the piston, and at the same time opens the opposite side of the piston to the exit pipe 1.

Fig. 204.



YULE.

Fig. 204. is a rotatory engine invented by Mr. Yule of Glasgow, and he has had it in operation working smoothly for some years. It consists of a cylinder C, in which upon the axis A, revolves another eccentric cylinder B, fitting tightly by means of packing at the line of contact. D is a diaphragm, which slides vertically in strong guides and rests upon the upper side of the revolving piston B. The steam is admitted by either of the pipes S^1 S^2, according to the direction the engine is intended to revolve in, the slide valves at the lower end of the steam pipes being regulated accordingly. E is the eduction pipe. In the figure the steam is represented as entering by the steam-pipe S^1, the valve of which covers the eduction port, and admits the steam to press upon the diaphragm D, and the piston B. The steam from the pipe S^2, is at the same time shut off, and the eduction on that side of the piston opened, and there being nothing to counterbalance the pressure of the steam on the other side of the piston, and the diaphragm being incapable of any lateral movement, the piston B is made to revolve in the direction of the eduction port. If motion in the contrary direction be desired, it is only necessary to reverse the valves.

We have already referred in page 3. to the rotatory engine, contrived by Mr. Pilbrow, which consists of a wheel resembling a small overshot water-wheel, against which steam is projected, as in Branca's engine. An engine of a similar kind has lately been brought forward by Mr. Corde, but we have not been able to learn that it has met with any success in practice. These engines operate by the impulsive action of the steam, and although steam in issuing from an orifice imparts a momentum to its particles equivalent to the mechanical effect realized by a pressure engine, yet the recovery of the power implies a velocity of rotation such as cannot be attained in practice with convenience. Mr. Pilbrow seems to imagine that he realizes some occult powers by this form of engine, and that by the use of a certain form of cavity he doubles the power; but no form of cavity can extract from the steam a greater power than there is in it, and the form of cavity cannot diminish the loss and inconvenience incidental to the great velocity with which the machine requires to move. In spite of these defects, however, we think something will one day come of this principle; and we therefore here set down some extracts from Mr. Pilbrow's patent, which will show the considerations by which he was swayed in the device to which we have referred:

" The properties of steam have hitherto been considered of that peculiar nature as to render it impossible to obtain its full power and extreme duty from expansion, except by using it according to the present system; that is, by letting it into a hot and close cylinder on a piston, and stopping its further entrance by cutting it off, to allow it to expand. Feeling, however, a strong conviction that the whole power was to be obtained by some more simple means than the present costly, complicated, and ponderous machinery, and that a power so easily raised need not be so laboriously applied, I undertook a long series of experiments to discover how this might be done. I first commenced on the most simple form of engine known to us, that of Hero's, and ascertained the true causes of its loss of power; and found, after many inventions to obtain from this simple machine the full power and duty from expansion, that, though I could considerably increase its power by a spiral form of arm, yet that I could not obtain the whole duty from expansion; and, consequently, that an engine on this principle could never be brought to compete with Mr. Watt's condensing engine. The failure, however, of my plans to obtain these results, disclosed to me the remarkable fact, that a current of steam in rapid motion — that is, issuing from an orifice — loses, almost entirely for practical purposes, that power from lateral expansion which it possesses when cut off and allowed to expand in a cylinder. When I had confirmed this phenomenon by other experiments, I was satisfied that steam possessed an impulsive power of the utmost efficiency, entirely different from what had ever been supposed; for, its full expansive force not being given out laterally, must have gone somewhere; and, as it could only expand in the line of its issue, I became acquainted with this new and singular property of steam, that it possessed, in its mere velocity alone, a propulsive force from its lineal expansibility equal in power and duty to the gross effect obtained when cut off and allowed to expand under the best circumstances. I had next to transmit this new principle of steam power to machinery, with the least possible loss from friction and other deductions, by some engine as simple as the principle; and this I supplied as hereinafter described. Having found, however, that there is as great a difference in the duty of steam, by the peculiar manner in which it is applied by its velocity, as is found in effect in the application of water, I shall first describe a few experiments, being some of those which led to my invention, to show the accuracy required. The operation of Barker's mill, and of Hero's emission engine, is well known; and though there is no resemblance between their moving powers — the one acting by gravity, the other by repulsion — there seems to be a strict analogy between their results, proportioned to the power and velocity of each; so that, whether water or steam be used in the following experiments, the modes of action being similar, the operation and direction of the arm will be the same: and it will be seen hereafter, that I obtain, by my application of the velocity of steam, the same duty therefrom as is obtained by the best overshot water-wheel — namely, a clear available effect of about two-thirds at least of the whole power of the steam employed; that is, two-thirds of its power and of its extreme duty from expansion; the steam being expanded, in my application of it, so low as the atmosphere in high-pressure engines, and to the vapour-point, or state of condenser vacuum, in condensing engines; degrees of attenuation which cannot be obtained by the present system, on account of the piston.

" When arms on Hero's principle are used in the usual way, the arms will revolve by unbalanced pressure; but when a flat plate is attached immediately before the orifice, the steam will impinge thereon, and, being broken up, will change its course as therein represented, and the arm will become stationary, showing that the force of impingement equals that of unbalanced pressure. If, however, a cavity be fixed, instead of the plate, opposite the orifice, at such an angle that the injet of steam can be returned by its reaction clear of the arm, without impinging thereon, the arm will revolve in the contrary direction to that of the previous unbalanced pressure, with more power than that with which it revolved the contrary way previous to the cavity being fixed thereon; proving that the cavity not only received the same amount of impingement as the flat plate received (which was shown to be at least equal to the unbalanced pressure), but by this peculiar injet and reaction or reissue of the steam, its *whole velocity* was *arrested*, and the cavity thus acquired another power of equal amount, sufficient to overcome the effect of unbalanced pressure only. But if the steam, on its reissue or reaction from the cavity, is permitted to impinge at all against the arm, the arm will then only revolve in the opposite direction, with power diminished in proportion to the amount of such impingement; and if all the steam on its reissue or reaction from the cavity is allowed, by altering the angle of the cavity, to strike fully against the arm, the arm will then remain stationary as when the flat plate was used.

" When I had discovered how this double power was to be obtained by arresting and transferring the whole velocity of the steam by such peculiar injet, and its clear reaction or reissue, and how its full effect might be impaired or wholly neutralised, as just described, I found myself possessed of a new method of applying the power of steam by its velocity alone; and this became the germ or principle of my improvements in the steam engine; for, to carry it out, I had only to invent such machinery as would give me this double power in the same direction of motion, without deduction for the unbalanced pressure in the experimental arm, to counteract the full effect of the whole force of the velocity, and also without loss of power from another source — that of my back-action or impingement of steam against the backs of the cavity next in succession. The following, therefore, is a description of the engine or apparatus by which I propose to effect these objects : —

"It is a section of a case, with a wheel fitting within, about half an inch all round, and revolving within the case. This case, for a high-pressure engine, may be made of cast or sheet-iron, of suitable thickness to resist the pressure of the atmosphere caused by a partial vacuum from the rapid action of the steam wheel. The whole of the inside should be made perfectly smooth, to prevent friction of the used steam when it re-issues from the cavities. For a condensing engine the case must be made strong enough to resist the atmospheric pressure. At those parts where the jets of steam are admitted, several cavities are made with or attached to the inside circumference of the case, for the purpose of receiving the used steam, and returning the same into the cavities of the steam wheel; and where a double row of cavities are used round the steam wheel, the rows of cavities in the case must be reversed accordingly. These cavities in the case must be placed in such a position to the cavities of the steam wheel that, on the used steam issuing therefrom and rushing into the cavities of the case, it may be returned therefrom into the cavities on the steam wheel at the same angle as that at which the steam first issued from the jet-pipes, and the used steam will then, as the wheel revolves, be thrown out at the eduction passage.

"The periphery of the steam wheel is formed by a series of cavities all round of the same dimensions, for the reception of one or more jets of steam. The size of the cavities in the wheel is three quarters of an inch deep, by one and a half long, and half an inch wide."

The method adopted to determine the best velocity is this: The velocity with which steam at 60lbs. pressure above the atmosphere rushes through an orifice is known experimentally to be about 104,490 feet per minute. The difference between this and the velocity of the periphery of the wheel gives the velocity of impact of the steam on the cavities of the steam wheel, and the power or pressure exerted on the wheel, being proportional to the square of the velocity of impact, the power of the engine can be calculated for various velocities of the wheel. Mr. Pilbrow has done this, and finds that "the greatest results are obtained when the wheel revolves at precisely one third of the velocity of the steam, or 34,830 feet per minute."

We have now given sufficiently copious extracts from Mr. Pilbrow's specification to explain the principal features of his new engine. In practice Mr. Pilbrow has not been able to make his engine succeed, and we do not believe that, by the plan proposed, he will be able to make a good, durable, and economical engine. He has not yet, at least, proved that his engine will realise nearly the power he anticipates from it. To make a few experiments on the force of impact of a jet of steam on surfaces at rest, and from that to theorise on the mechanical effect of steam rushing into and rebounding from cavities in rapid motion ; — to calculate the velocity of impact on one surface, and of rebound from another, as if it were a solid and perfectly elastic body, whose laws of motion are exactly known, is a method of proceeding that can only lead to error, or at least can never bring us with certainty to the truth. We agree with Mr. Pilbrow, that the whole power of the steam is expended in giving velocity to its own particles, and, theoretically speaking, the same power ought to be extractible from them. In Mr. Pilbrow's engine, however, we have seen that the periphery of the wheel is to move with one third of the velocity of the steam, leaving only two thirds of the velocity to produce mechanical power. Now, Mr. Pilbrow himself says, that the mechanical power produced is proportional to the square of the velocity of impact, and the square of $\frac{2}{3}$ is $\frac{4}{9}$, or scarcely one-half. So that here is fully one-half of the whole mechanical effect dissipated at once: but this is not all; for when the steam strikes the periphery of the wheel, with two-thirds of its actual velocity, it must, by the laws of elastic bodies, rebound with the same velocity from the wheel; that is, it will rebound with an actual velocity of one-third, while the wheel moves in the opposite direction with an equal velocity. There is, therefore, this velocity of one-third of its original velocity still remaining in the steam, and unextracted after impact. One-third of the velocity corresponds to one-ninth of the mechanical effect. This, therefore, is also lost. We believe, indeed, that in the later modifications of the plan, it has been Mr. Pilbrow's object to have the steam reflected from the wheel, at a velocity equal to that of the wheel's rotation, so that it will, in effect, be brought to a state of rest; and professor Mosely has made a number of calculations to show that there is no loss of power if this condition be fulfilled. But the condition implies that the particles of steam are perfectly elastic, which is uncertain, and involves the necessity of the wheel moving with half the speed of the effluent steam, which is impossible in practice. A velocity of one-third of that of the steam, viz. 34,830 feet per minute, at the periphery is 3,166 revolutions per minute, — a velocity sufficient to make the engine fly to pieces. Mr. Pilbrow himself could not avoid seeing this objection, and accordingly he has attempted to prescribe a remedy. He proposes to make the wheel go slower, by which means the steam will rebound from its periphery with a correspondingly greater velocity, and is to be made to impinge on a cavity in the case similar to those in the wheel. From this it will again rebound, and strike the wheel, and again be returned to another cavity in the case, and thence once more impinge on the wheel. These alternate saltations from the wheel to the case, and from the case to the wheel, are to be continued till the velocity of the steam has been entirely expended in imparting power to the wheel. We believe few persons will be able to refrain from a smile, when they contemplate the steam performing these fantastic gyrations. We suspect that it will be more apt to take one long jump to the exhausting port, and make its way off the stage as quickly as possible, instead of stopping to complete so many ingenious evolutions. It is but justice to Mr. Pilbrow to say, that he is very doubtful of the success of this part of his plan. His having ventured to propose it at all is a strong proof to us that he felt very strongly the force of our objection to the enormous velocity proposed to be given to his steam wheel.

Such, then, is a slender specimen of the rotatory engines which have at various times been projected for the supercession of the cylinder engine : many of them display much ingenuity, and, indeed, on no single subject perhaps has so much ingenuity been expended: nevertheless, up to the present time, no rotatory engine has been contrived which can be esteemed preferable to the common engine. We have already expressed our conviction that this will not be always so; but we believe an efficient rotatory engine must be sought rather among dynamical than statical resources. Pilbrow's engine, though it has weighty faults, is a movement in the right direction, and an engine on the impulse principle permits the benefit due to expansive action to be realised. From engines of the Ælopile class a beneficial result is hardly to be expected, at least if made in the ordinary method; for by such engines there must be a loss of effect if the steam leaves the revolving arm with a greater velocity than that with which the arm moves, and this, unless by a combination of Ælopiles, it must do at all ordinary pressures and speeds.

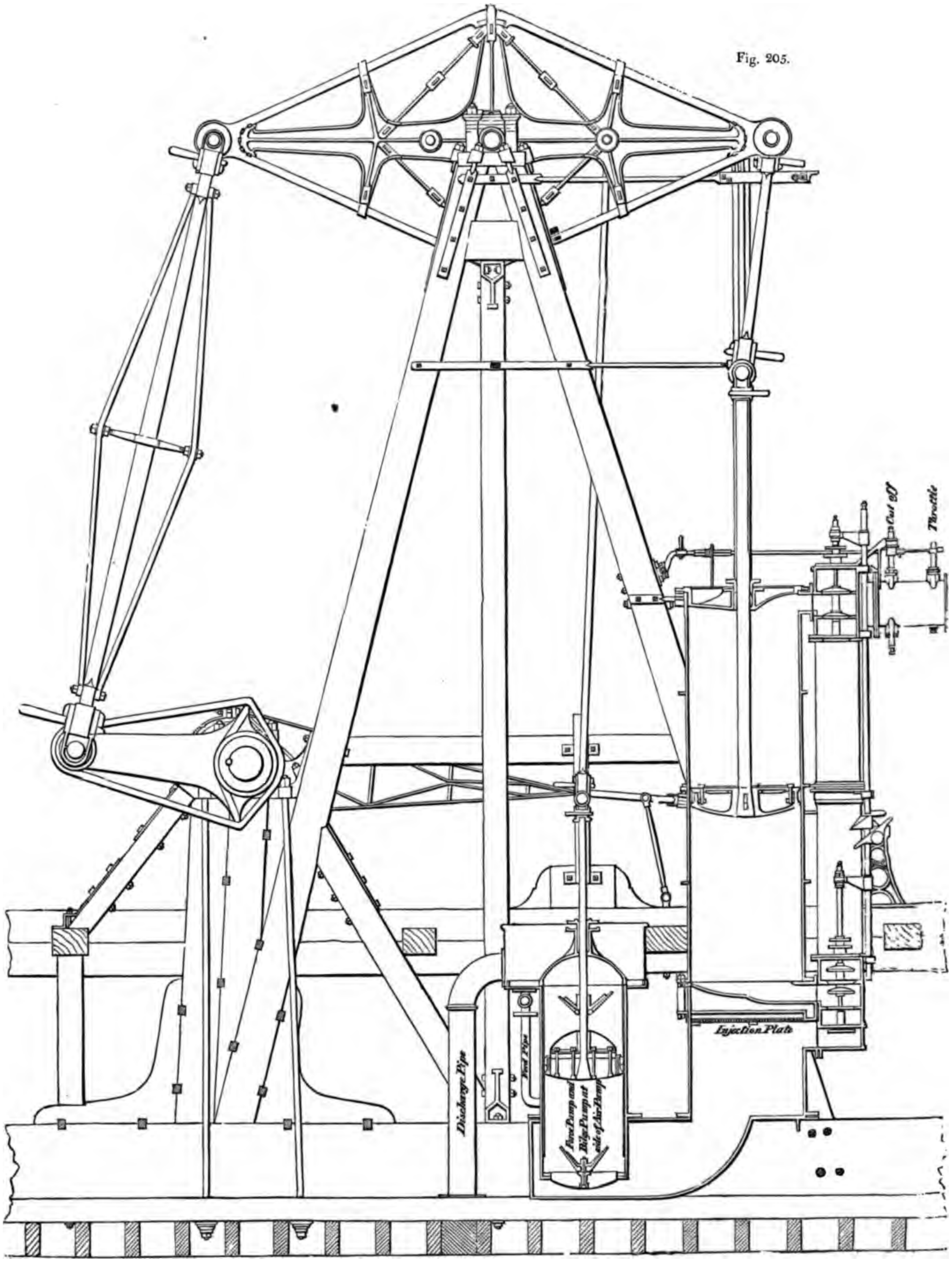
AMERICAN ENGINES.

The engines made in America are for the most part of a very rude and primitive description; yet the performance of the American steam vessels is such as to make them fully a match in point of speed to the best steam vessels of English construction. Their efficient performance is partly perhaps due to the high pressure of steam employed, and partly to the peculiarities of American river navigation, which are such as to enable a large sized vessel to subsist with a very moderate draft of water. On the Mississippi and its tributaries most of the engines employed are of the high pressure kind: a hundred pounds upon the square inch is esteemed a moderate pressure, and sometimes the pressure is raised as high as a hundred and fifty pounds on the inch. The engines employed in the vessels on the Hudson are for the most part condensing engines. Some of them have horizontal or inclined cylinders; in other cases the cylinder is placed above the shaft, with side-rods extending from the ends of a cylinder cross-head to cranks on the shaft beneath; while in a third variety a beam is employed as in the ordinary land rotative engine. Sometimes two engines are employed; but very often only one, the crank being carried over the centre by the momentum of the vessel. A few sets of engines for steam vessels have been made in America after English examples, and some of these specimens, which have come under our observation, are highly creditable performances; but most of the engines made in the country are of the quality and complexion of that of the North America. We subjoin a view of the machinery of that vessel; and we may here set down a few of the chief dimensions: — Diameter of cylinder, 43 inches; length of stroke, 11 ft.; length of keel, 200 ft.; breadth of beam, 25 ft.; diameter of paddle wheel, 27 ft.; length of float, 10 ft.; dip of float, 27 in.; pressure of steam, 50 lbs.

The framing of this engine is of timber: the working-beam consists of a cast-iron skeleton frame trussed with wrought iron; and the crank and connecting-rod are both trussed with malleable iron rods. The beam is very short in proportion to the length of the stroke, and the place of the parallel motion is supplied by guides, the piston-rod being coupled to the beam by a long link, to enable the guides to operate efficiently. The several pieces composing the wooden framework which supports the crank shaft are keyed together with wooden keys, and bound with iron knees and plates of iron, to make the whole stiff and firm. The valves are double spindle valves, so that they are kept in equilibrium : this valve has the disadvantage that the valve-spindle expands more than the valve-casing, both from its higher temperature and the greater expansibility of the metal. Such valves, therefore, though tight when cold, will not be tight when hot. The cut off or expansion valve consists of a disc turning on a centre, like the throttle valve, and set in the steam-pipe, which it exactly fills when closed: in the rest of the engine there is little that is peculiar. The trussed beam might, it appears to us, be adopted with advantage in all large beam engines in this country, as it is not merely lighter than the cast-iron beams commonly used, but stronger and more safe. The trussing of the crank and connecting-rod we look upon as superfluous; and it must be difficult when they are trussed to keep those parts clean.

In many of the American steamers the engines and boilers are placed upon the deck, and beneath the deck a saloon extends the whole length of the vessel, for the accommodation of passengers. Most of these saloons are magnificently fitted up: many of them are upwards of 150 ft. long, 20 ft. wide, and 12 ft. high; and the accommodations are in every respect most

Fig. 205.



Scale ¼ inch=1 foot.

ENGINE OF AMERICAN STEAMER, NORTH AMERICA.

complete and commodious. The paddle-wheels are generally entirely constructed of wood, with the exception of the centres, to which the arms are bolted, and which are of cast-iron. The usual number of strokes per minute, with an 11 ft. stroke, is from 25 to 27, so that the piston travels at a great velocity. In the vessels on the Mississippi the paddles are made with a clutch or friction-strap, so that they may be thrown out of gear, and the engines may be turned so as to feed the boilers when the vessel is alongside a wharf, without moving the paddle-wheels. The steam vessels plying on the Mississippi are chiefly built at Pittsburg and Cincinnati: these vessels are much inferior to those plying from New York to Albany, and to Providence; and they are managed in the most reckless manner. Mr. Stevenson, speaking of one of these vessels, says, "She was steered close in-shore amongst stones and stumps of trees, where she lay for some hours to take in goods: the additional weight increased her draught of water, and caused her to heel a good deal; and when her engines were put in motion, she actually *crawled* into deep water on her paddle-wheels: the steam had been got up to an enormous pressure, to enable her to get off, and the volume of steam discharged from the escapement-pipe at every half stroke of the piston made a sharp sound, almost like the discharge of fire-arms, while every timber in the vessel seemed to tremble." The numerous explosions of boilers on the Mississippi cannot excite astonishment amid such provocations as that here narrated. The boilers are not calculated to withstand any very high pressure, even when new. Of the best form of American boiler we have given an example in page 56; such a boiler would not be considered safe in this country with a greater pressure than 10 or 12 lbs. on the inch.

THE LOCOMOTIVE ENGINE.

The whole of the engines we have yet described at any length are condensing engines—the steam, after having urged the piston to the end of its travel, escaping into the condenser, where, by the abstraction of heat, it is reduced again to the form of water. The locomotive engine, however, is not of the condensing, but of the high pressure kind, the steam escaping, after having given motion to the piston, into the atmosphere. We have already explained that there is a loss of effect incidental to the use of the high pressure engine, but it would be most inconvenient to carry the large quantity of water a locomotive would require for condensation, and the rush of waste steam acts beneficially by blowing the fire; so that in this case to obviate the loss of effect incidental to the omission of condensation would involve the introduction of greater evils.

The locomotive engine of Messrs. Bury, Curtis, and Kennedy is a very complete and elegant piece of mechanism; and we may here give an explanation of the several parts of the merchandise engine of these eminent makers, which is represented in detail in Plate 23. *Fig.* 1. is a sectional elevation; *fig.* 2. is a sectional plan, *x x* being the principal line of section on which *fig.* 1. is shown; *fig.* 3. is a transverse section through the smoke-box. The same letters of reference are used throughout all the figures; and to render them more explicit, several parts are shown which do not properly come into view on the lines of section. A is the fire-box: it is made of wrought iron ⅜ of an inch thick, except the tube-plate, which is half an inch thick. The joints are welded wherever they are in contact with the burning fuel, as a rivetted joint, from its presenting a double thickness of metal, will not long resist the intense heat to which it is exposed. The fire-box is of a cylindrical form, with its back flattened to receive the ends of the tubes: the top is hemispherical, surmounted by a small dome, into which the upper end of the steam-pipe is carried, to obviate priming. B are the fire-tubes, of which there are 96, 2 in. diameter, and 9 ft. long. It will be seen, from the transverse section, that the tubes are so disposed as to concentrate the heat towards their centre, with the view of making a current from the outside of the tubes, where the water is colder, towards the bottom of the tubes, whence it will rise when heated up among the tubes. Partly for this reason, and also to prevent the tubes from being uncovered by the centrifugal recession of the water when the engine is travelling upon sharp curves, the upper row of tubes follows a circular sweep, the highest point being in the centre of the engine.

C. Is the smoke-box. D. The regulator. E. The steam-pipe, 3½ inches diameter. F. The safety-valve and spring pressure-gauge, 2½ inches diameter. G. The locked-up safety-valve, 2½ inches diameter. H. The damper. I. The buffer-bar. J. The steam-whistle. L. The steam-cylinders, 13 inches diameter, 18 inches stroke. M. The force-pumps, plunger 2 inches diameter, 18 inches stroke. N. The cranked axle; the journals are 5 inches diameter, and 7 inches long: the bearing of each crank is 5½ inches diameter and 3½ inches long. O. The connecting-rods, oval-shaped, 2 inches by 2½. P. The axle of the front wheels, 4½ inches diameter. Q. The springs. The springs for the cranked axle are composed of 16 plates, together 4½ inches deep at the centre; those for the front axle are composed of 10 plates, together 3⅞ inches deep at the centre. *a a.* are the steam-pistons of gun-metal: the packing consists of two rings of cast-iron segments, forced outwards by brass wedges and steel springs. The piston-rods are 2 inches diameter. *b b.* are the inlet passages for the steam, 1½ × 6½ inches, *c.* The outlet passages for the steam, 1⅞ × 6½ inches. *d.* The slide valves. *d′*. The slide-valve rods, 1 inch diameter. *e.* The pendulum-rods for carrying the ends of the eccentric rods, *f.* The shaft to which the eccentric levers are fixed, *g.* The shaft connecting the motion of the lever *h*, and the rod *i*, to the shaft. *h.* The guides for the piston-rods. *i.* Steadying pieces for the guides. *j.* Shaft carrying the steadying pieces. *k l.* The rods for moving the slide-valves. *k′ l′.* The levers of the hand-gear. *m.* The shaft carrying the valve trappings. *n.* The lever for working the valves. *n′.* The lever worked by the eccentrics. *p.* The eccentrics for the retrograde motion. *q.* The eccentrics for the advancing motion. *r.* The pipes (2 inches diameter) connecting the force-pumps with the tender. *s.* The cock for letting the water out of the boilers. *t.* The rods (1⅝ inch diameter) for coupling together the front wheels and the driving-wheels. *u* is a lead plug, placed at the culminant point of the dome-shaped top, and which will melt before any other part of the fire-box is left dry.

The framing of this engine is that which has been so long used by Messrs. Bury, and which is known as the inside framing. Mr. Bury claims for the inside framing a great superiority over the outside, on the ground that it forms a stronger connection between the cylinder, crank axle, and other moving parts, and bears all strains and concussions without throwing any of them upon the boiler. The following is Mr. Bury's comparison between the inside and outside framings:—

"The advantages of the inside bearing are best described by comparing it with the ordinary outside framing when submitted to the principal strains which it has to resist. The most important is that caused by the whole power of the engine acting as a direct strain upon the crank as it passes over either centre. With the inside framing, the centre line of the connecting rod is only 10 inches distant from the centre line of the frame, and the total distance between the bearings is 43½ inches; but when the framing is outside the wheels, these dimensions are necessarily 20 inches and 72 inches respectively, and the effect of the strain upon the crank in this case would be to its effect with the inside framing as 14 is to 8. For this reason, when the principal frame is placed outside the wheels, it becomes necessary to have an additional inside framing, to prevent the friction of the axle; these additional inside frames not only cause an increase of friction on the bearings of the cranked axle, but also throw a considerable strain on the boiler, which then becomes the medium of connection between the inside and outside frames, the inside frames being fixed at one end to the bottom of the smoke-box, and at the other end to the fire-box; while the principal frame is attached by long brackets to the body of the boiler. The fact that the use of four additional inside frames occasions six bearings on the axle (that axle being only 6 feet long), renders the system of principal outside framings so objectionable, that that circumstance alone should suffice to cause their rejection; for it is well known to practical men that it is impossible to key so many bearings perfectly true, and to maintain them so, when the engine is working; and even if this precision were attained, the aggregate friction on the four inside and the two outside bearings would be much greater than when it is all thrown upon two bearings; because, in the first place, all the friction due to the weight of the boiler is borne by the two outside bearings alone, and that which results from the pressure of the steam, through the medium of the connecting-rod, is thrown upon the four inside bearings: the pressure upon the outside bearings is vertical, and the mean pressure upon the inside bearings is nearly horizontal. So that if, instead of acting separately, these two amounts of pressure were thrown on the same bearings, the friction would only be due to the resultant of the pressures, and would consequently be much reduced. The friction on the cranked axle, having only two bearings, as, where a single inside frame is used, will be, under ordinary circumstances, that due to the resultant of the vertical and horizontal pressures, or,

$$\frac{\sqrt{12646^2 \times 3000^2}}{8} = \frac{13,000 \text{ lbs.}}{8} = 1625 \text{ lbs.}$$

In addition to the friction resulting from these forces, there is a considerable pressure on the bearings, arising from the tightness of the brasses; and it is evident that the friction arising from this cause will be three times greater with six than with two bearings. Another important feature is the strain to which locomotive engines are liable, from the pressing or striking of the flanges of the wheels against the rail when travelling in a curve. In engines with the bearing inside the wheels, the weight of the boiler has a tendency to bend the axle down in the centre; while the pressure of the flange against the rail acts upon it in a contrary direction, and thus one strain counteracts the effect of the other. If the bearing is outside the wheel, the weight of the boiler tends to bend the axle upwards, and a strain upon the flange of the wheel acts in the same direction, and in addition to it."

The position of the bearings inside the wheels is of great practical advantage in case of the fracture of the cranked axle, as the weight on the bearings presses the flange of the wheel against the rail, and assists the length of the journal in keeping it from being thrown off the rail. Instances have occurred on the London and Birmingham Railway, when an axle has broken, that not only have the wheels remained on the rails, but the driver has been enabled to proceed with the train to the nearest station. The stiffness of the single inside framing is not only a remedy against the excessive wear and tear which is consequent on a less perfect union between the parts of the engine, but its simplicity allows the whole machinery to be arranged in a more compact form, and constructed with greater solidity.

in the ring would be exactly counterbalanced by corresponding ellipticity in the cylinder; and not only so, but the next rings that happened to be put in would fit with as great truth as the most hair-breadth system of compensation could possibly effect, since the alleged unequal expansion of the ring would then correspond exactly with the shape to which the cylinder has by that time worn.

It is abundantly obvious, however, that the effect upon the cylinder of the unequal expansion might be altogether neutralised (were it ascertained to have any proper existence), by using two rings instead of one, the position of the joints being 90° apart. It is not uncommon to have the rings placed with the joints on opposite sides of the cylinder, or 180° apart: an arrangement only useful to prevent the passage of the steam through the single break (an object which might be easier attained in another way), and incapable of exerting a correcting influence on the above-named inequality.

Under the third modification of this description of packing, we class pistons in which each ring is still in one piece, but in which some of the above modes of compensation are had recourse to. The common method is, simply to turn the ring about one third thinner toward the part where the joining is made; two rings are commonly used, the position of the joints being as above described, and instead of the rings being turned of greater than the required diameter, and then sprung in, the requisite elasticity is given by hammering the thicker semicircumference on the hollow side. Of course, the same method may be taken with rings of uniform thickness, and to derive the full effect of the hammering, it might be well to retain the original skin of the casting on the inside of the ring. The advantage of giving the requisite elasticity by hammering rather than by compressing the ring, lies in the more perfect circularity ensured by the former; but were the precaution taken to turn up the compressed rings in the lathe, this difference would no longer have place; and this is now generally done in addition to the hammering.

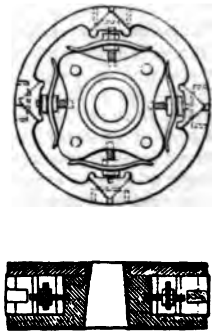
This arrangement has been generally found to work very well; but perhaps not better than the preceding more simple variety, when the workmanship of both is equally correct; and to deficiency in this particular, we apprehend, must be ascribed any disadvantage which the latter, as sometimes constructed, have been found to labour under. Numberless methods have been taken to prevent the escape of the steam by the open end joints which this species of ring exposes; frequently hemp packing is put behind the rings; sometimes they are merely cut without any further provision; and sometimes the evil is left in its full magnitude, without any attempt at a remedy; but by far the best plan, undoubtedly, is to rivet a piece of brass or iron, previously fitted to the proper curvature, to the inside of the ring on one side of the break, so that it shall apply correctly to the other side, and slide along steam-tight as the ring expands by wearing. Inattention to this simple precaution has been the occasion of great inconvenience, and has even led to the substitution of a much more expensive, though not in reality much more efficient system.

Deferring our remarks on some important modifications of this construction till we come to consider the pistons in detail, we proceed to consider the second principal division of our subject, comprising many subvarieties: we mean, that class of pistons where artificial springs are used, acting in most cases by the intervention of blocks or wedges. The most common construction is as follows: — Two strong cast-iron rings, of such dimensions as to have no perceptible elasticity themselves (say from 1¾ in. to 2½ in. square in the cross-section), are cut, each into from three to six or eight segments, according to the size of cylinder, or other regulating circumstance, placed the one above the other, so as to break bond at each joint, and at each break part of the ring is cut away to admit the introduction of a wedge usually of the angle of 90°, the point of which may be ¾ in. from the surface of cylinder: a common elliptical spring is then introduced between the body of the piston and the back of the wedge. Sometimes, instead of a wedge, a simple block is used, or the spring presses immediately upon the back of the ring.

In the original form of this piston, as constructed by Barton, the points of the wedge came in contact with the cylinder, being situated in the periphery of the piston, and, in order to prevent their injurious action in grooving the cylinder, it was proposed to make them of softer metal; and, we believe, it is to Tredgold that we are indebted for the suggestion of the above-described greatly improved modification. In this description of piston, the mode of action of the wedges is what seems principally to require investigation. When the points of the wedges are not in contact with the cylinder, the mode of action is sufficiently obvious; the intervention of the wedge serving simply to multiply the energy of the springs on the principle of the wedge, as a simple mechanical power. Of course, the more acute the angle of the wedge, the greater force is imparted to the springs, on the principle of virtual velocities; and were the segments only required to expand indefinitely, instead of expanding and contracting by turns, to suit the inequalities in the cylinder, then a very acute wedge might be used: but as the wedge must be ready to spring back, to allow the packing to yield when it comes to a tight part of the cylinder, as at the top and bottom of the stroke, it is plain that the inclination must be considerably greater than the angle of repose; it is seldom, however, made less than 80° or 90°, but we believe a considerably sharper angle would be found to answer. Considering now, for a moment, the case in which the points of the wedges come in contact with the cylinder, it might seem, at first sight, that they would exert no pressure at all upon the adjacent segments; and such would be the case, were it possible for them to wear no faster than the rings themselves; a little consideration, however, will show that this can never be the case, as the wear upon the wedge must be to that of the ring, in the proportion of the side to half the base of the wedge; that is, in the case of a right-angled wedge, as the diagonal to one of the sides of a square: were the wedge and cylinder then to be made of the same material, the wear of the cylinder opposite the wedge would exceed that of the rest of its surface, in the above proportion, or probably in a somewhat higher ratio, arising from the different grain of the metal composing the wedge. The wedges however are almost always made of gun metal, which serves in a great measure to neutralise what would be otherwise the injurious tendency of this arrangement.

With these preliminary remarks, we now proceed to consider, in detail, several of the varieties of piston that have come most prominently under our notice, the better able to decide upon their respective merits from the general principles we have laid down.

Fig. 207.



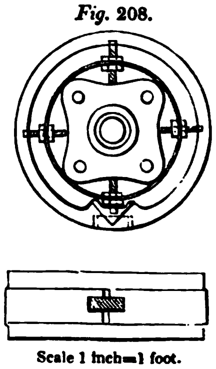
Scale 1 inch=1 foot.

LOCOMOTIVE PISTON BY MESSRS. FORRESTER AND CO.

Fig. 207. represents two views of the locomotive piston made by Messrs. Forrester and Co., Liverpool, for the Grand Junction Railway. The peculiarity of construction and mode of action is apparent from inspecting the drawing. By fitting a tongue piece, or tenon, into a corresponding mortice, in both wedge and ring, it is intended to prevent the passage of steam at the breaks of the segment, instead of the common method of using two rings, each of half the thickness, with the joinings of the one ring placed midway between those of the other. We believe this construction has been found to answer perfectly; but this is not paying it a distinguishing compliment, as we shall soon see that the same may be said of certain other descriptions, about which there is not above one fourth of the workmanship here displayed. In fact, display is the very idea which this piston suggests; the elegance of the design, the slenderness of the working parts, and the extreme accuracy of workmanship, necessary to its action — and which the Messrs. Forrester are never known to spare — rather serve to point it out as a pretty engineering toy (not without its share of usefulness, at the same time) than as a plan likely to be either extensively adopted or generally approved of. In the first place, there can be no doubt, that the prevention of leakage by the joints would be at least as effectually accomplished by having two rings arranged as above described; a method that will generally be found, in the hands of common workmen, to be of much easier execution; very great nicety being required in the fitting of the sliding pieces into the mortices, and the slightest imperfection at first having a tendency to wear worse from the constant passage of the steam. Again, as the sliding pieces must move forward faster than the segments (when the wear commences) in the proportion of the diagonal to the side of a square, as can easily be demonstrated, it follows, that the pieces themselves, and consequently the part of the cylinder corresponding, must wear faster too; and thus is the cylinder liable to be worn unequally. The extreme slenderness of the springs, and the slight pressure which they are generally required to exert, may indeed, for the most part, prevent this inequality from being readily perceptible; but it is evident that the action is in some measure similar to that of a flat-pointed wedge pressed forward by a spring, and itself in contact with the cylinder.

We shall further find, on comparing this piston with more simple varieties, that it is unnecessary to divide the ring into so many segments. Such a complete system of adjustment and compensation might have been very beneficially employed during the nonage of steam cylinders; but is proved to be superfluous in the present state of machinery, by the fact that a ring cut in a single place is found to give perfect satisfaction.

Fig. 208.



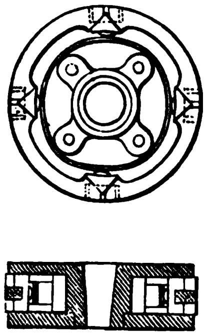
Scale 1 inch=1 foot.

LOCOMOTIVE PISTON BY MESSRS. DIRCKS AND NELSON.

Fig. 208. represents plan and section of a piston manufactured for common and locomotive engines, by Messrs. Dircks and Nelson, late of the Etna Foundry, Liverpool, differing from the above, in having only one wedge and break in the ring instead of four. The set screw, on the side farthest from the wedge, might be omitted; the two side screws serve in some measure to compensate for the sluggish action of the right-angled wedge, which seems rather to press the ring against the cylinder at the point immediately adjacent than to force it open, and thus make it bear equally all round. A more acute wedge would propagate the pressure of the spring more readily throughout the entire circumference. A circular spring, like that used here, while it possesses several conveniences, is yet less delicate and perfect in its action than the common elliptical kind; and perhaps, too, less easily re-set or re-tempered.

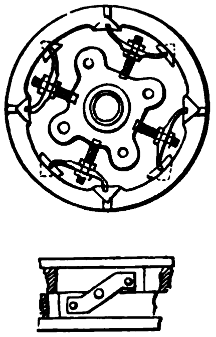
Very similar to the first variety is that shown in *fig.* 209. We doubt whether the slight superiority in point of simplicity gained by doing away with the adjusting screws, and substituting a single spring hoop, be not more than counterbalanced by less perfect action. A method intermediate between the two last is sometimes adopted; the packing ring is cut, and a sliding piece and wedge employed in two opposite places, and a circular spring, with set screws, acts upon each.

Fig. 209.



Scale 1 inch=1 foot.
LOCOMOTIVE PISTON.

Fig. 210.

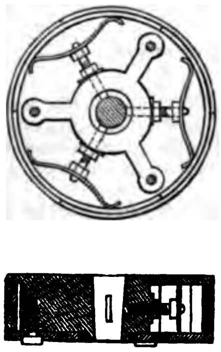


Scale 1 inch=1 foot.
LOCOMOTIVE PISTON BY BURY, CURTIS, AND KENNEDY.

Fig. 210. represents a plan of the piston so extensively known as Edward Bury's locomotive piston. The distinctive feature in it is, that each spring acts upon one wedge in the upper ring, and another in the lower, the centre of the spring, contrary to common usage, being made the "point d'appui," from the body of the piston. This variety is free from some of the defects of Forrester's, and when managed with care is found to work with great truth and accuracy. First cost of workmanship, unnecessary complication, considerable liability to derangement, are accompanying qualities which will be found to act more or less as drawbacks in different circumstances, and which by some may rather be deemed matters of financial than of engineering science. Among the great variety used on the Gloucester and Birmingham Railway, this description has been found to give the greatest satisfaction, while on some of the other lines they are in the course of being superseded by simple forms, which are said to be every way preferable. The peculiar contour of the springs involving, as it does, the difficulty of replacing them elsewhere than where they were first manufactured, is a point almost too insignificant to be noticed, but which, we doubt not, has tended to bring them into disrepute on some of the lines of railway above alluded to.

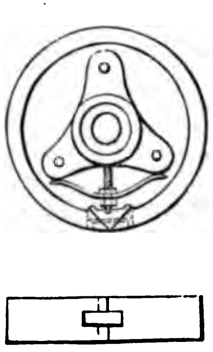
Fig. 211. represents a piston that has been much used by Messrs. Stephenson: it consists of three concentric rings, the two outer being rebated and morticed upon their edges, and together filling up the space between the flanges of the piston. The inner ring is equal in depth to the two outside rings. When the rings are turned to fit the cylinder and each other, they are hammered on the inside, to give them a tendency to spring outwards, and are then cut through, to allow them to expand. The divisions of the rings are placed so as to break joint. To provide for the wear of the outside rings, springs are placed at the back, which can be tightened up by means of screws bearing upon the centre part of the springs.

Fig. 211.



Scale 1 inch=1 foot.
LOCOMOTIVE PISTON BY R. STEPHENSON AND CO.

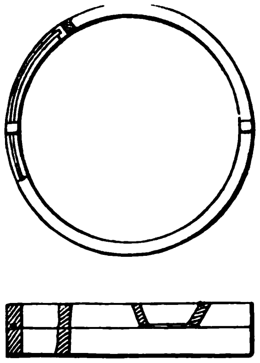
Fig. 212.



Scale 1 inch=1 foot.
LOCOMOTIVE PISTON, LIVERPOOL AND MANCHESTER RAILWAY.

Fig. 212. represents a kind of piston used on the Liverpool and Manchester Railway, very similar to *fig.* 208., or to those used on the Grand Junction Railway. As before remarked, the obtuseness of the wedge seems to be almost the only defect in this simple and elegant species of packing. We must, however, confess, that in urging this particular we form our opinion on theoretical, we had almost said, conjectural grounds, as we have never met with a more acute angle in a piston than from 80° to 90°. The pistons on the Liverpool and Manchester Railway are generally brass. This is an advantage in horizontal or inclined cylinders, as the softness of the material, and the greater lightness of the piston, considerably reduce the wear of the cylinder. Brass pistons have been, on this account, much used for locomotive engines; one drawback, however, to their employment, is, the inferior elasticity of the metal, which renders the employment of artificial springs necessary.

Fig. 213.

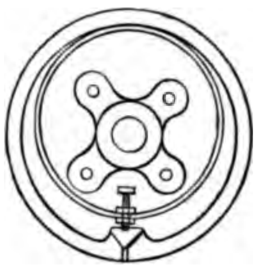


Scale 1 inch=1 foot.
LOCOMOTIVE PISTON, GREAT WESTERN RAILWAY.

Fig. 213. represents the packing-rings of Stephenson's locomotive piston, as we have seen them used on the Great Western Railway. The peculiarity of this piston consists in the two rings being grooved and tongued into each other in a manner similar to common flooring deals as we have already mentioned. In the published description of this locomotive we are told that this is intended to "keep them steady,"—an end that should, we think, be sufficiently accomplished by their being enclosed within the cylinder.

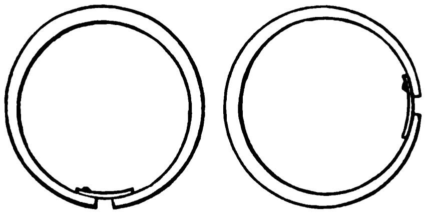
Fig. 214. represents the plan of a piston used on the South-Western Railway, bearing a considerable resemblance to what we have seen on the Liverpool and Manchester line. It is superior in simplicity, and at least equal in efficiency, to several of those we have figured. A modification of this kind is used with success upon the Runcorn Gap Railway, with this difference, that, opposite the set-screw, the ring is made perfectly flat for about the fourth of the circumference. The engines made by Sharp and Roberts for the French Railways are likewise fitted according to this modification.

Fig. 214.



Scale ½ inch=1 foot.
LOCOMOTIVE PISTON, SOUTH WESTERN RAILWAY.

Fig. 215.

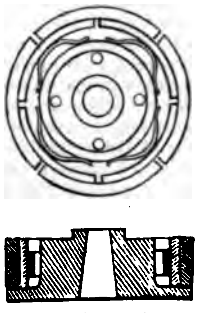


Scale 1 inch=1 foot.
LOCOMOTIVE PISTON, GLASGOW AND AYR RAILWAY.

Fig. 215. represents the piston adopted on the Glasgow and Ayr Railway, where it has superseded the more complex varieties. It is free from all or most of the defects we have pointed out, and has given much satisfaction in practice. The position of the rings, in being placed with the breaks, 90° apart instead of 180°, is one of those trivial but judicious arrangements which often determines the character of a mechanical contrivance.

Fig. 216. is a plan and section of piston similar to that used for the American or Bogie engine, manufactured for the Gloucester and Birmingham Railway, by Messrs. Nasmyth, Gaskell, and Co.—two packing-rings, ¾in. × 1¾in., each in three segments, pressed out by three elliptical springs with set screws, through the medium of an inner ring equal in depth to the two, and cut in three places. Mr. Nasmyth has constructed many of his locomotive pistons with spiral steel springs instead of the usual elliptical kind: they were found very liable to break, however, and are now almost entirely disused. We have seen hollow packing-rings constructed by Mr. Nasmyth, with the object, we presume, of obtaining a broad steam-tight bearing without increased weight.

Fig. 216.

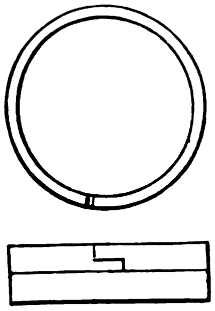


Scale 1 inch=1 foot.
LOCOMOTIVE PISTON BY MESSRS. NASMYTH AND CO.

These then are the principal specimens of locomotive pistons we have to give: we shall next describe some of the most approved pistons for marine engines, all of which are also applicable to land engines.

Fig. 217. represents a variety of packing manufactured by Messrs. Maxton and Co., Leith, adapted for marine engines. The specimen we have already given by these makers has an improvement introduced or patented several years ago by Mr. M'Dowall, of Johnston, near Paisley, which consists in cutting the rings in a slanting instead of a perpendicular direction. In Mr. M'Dowall's piston the ring is cut into several segments; and, as only a single ring is used, a sliding piece is checked in on one side, to break bond, and prevent the passage of the steam through the opening. That shown in the figure would be improved by the substitution of a single ring of sufficient depth, instead of two; and, by employing a sliding piece behind the joining, thus rendering the hempen packing unnecessary. The other forms of joining shown in the above figures are possessed of no particular interest, being somewhat difficult in execution, without corresponding advantage.

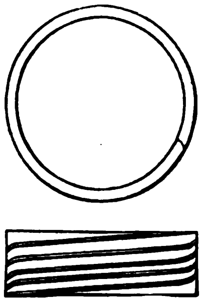
Fig. 217.



Scale 1 inch=1 foot.

PISTON BY MESSRS. MAXTON AND CO., LEITH.

Fig. 218.

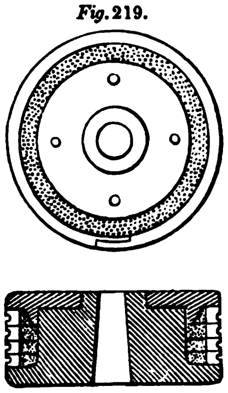


Scale 1 inch=1 foot.

JESSOP'S SPIRAL PISTON PACKING.

Fig. 218. represents Jessop's spiral metallic packing, as made several years ago by the late Messrs. Claud Girdwood, and Co., for two small subsidiary engines for the "Don Juan" steamer. On considering the action of the spiral coils, when the ring is compressed into a lesser diameter, it will be found that the tension of the springs is a minimum at the centre of the coil; while it increases towards each extremity in the ratio of half the number of coils to unity. This packing is but little used.

Fig. 219.



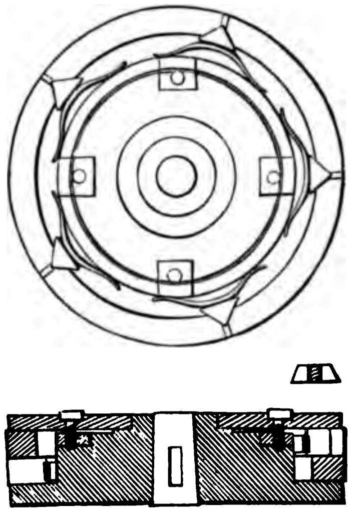
Scale 1 inch=1 foot.

PISTON BY MESSRS. CLAUD GIRDWOOD AND CO.

Fig. 219. represents an arrangement that was extensively adopted by Messrs. Claud Girdwood and Co. The packing consists of four rings, from ¾ to 1¼ square, according to the size of the cylinder, which may vary from 6 to 50 inches in diameter. In pistons of the latter dimensions the rings are turned fully two inches more in diameter, and afterwards cut in one place, and bent to the proper circle in a mould prepared for the purpose—the ends being half checked in such a way as to be steam-tight without the necessity of using packing behind, which, however, is frequently added. In order to bring the cylindrical surface of the rings sooner to an exact bearing, a groove is turned out of the outer circumference of each: this may help, besides, to keep the piston tight, by affording a lodgment for oil and tallow, and may in certain circumstances be of considerable use. In one instance within our knowledge this kind of piston has been at work, with occasional interruption, but little or no repair, for a period of ten years.

Fig. 220. represents plan and section of piston both for marine and land, manufactured by the Messrs. Maxton, of Leith. This may be regarded as a favourable, and at the same time, characteristic specimen of the most generally approved and widely adopted variety of packing in which separate springs are employed. The ease with which the springs may be bent and reset to the proper compass prevents set screws from being required: the only seriously objectionable point seems to be the expense of fitting and grinding steam-tight the ten wedges required. While, however, we may admire the capability of perfect adaptation to the form of the cylinder, which this piston presents, we must express our decided opinion, that a sufficient, if not, practically speaking, an equal degree of correspondence might be attained at a fraction of the expense. This, however, supposes the case of a new and perfect cylinder; but where that has been previously worn unequally by hempen packing, as is frequently the case, then this modification possesses decided advantages, and has, we believe, been repeatedly applied by the Messrs. Maxton in these circumstances, with great success. The use of wrought-iron nuts, fitted into the body of the piston to receive the junk ring screws, instead of tapping them into the cast iron, is a very obvious improvement, though not peculiar to Messrs. Maxton.

Fig. 220.

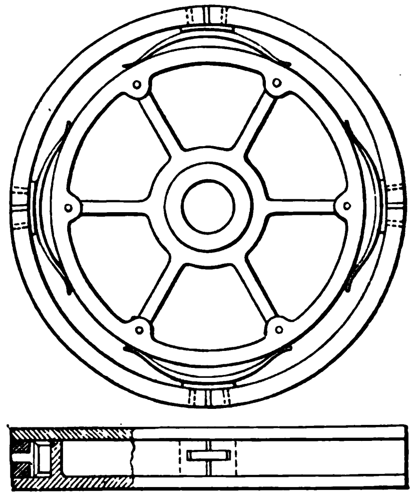


Scale 1 inch=1 foot.

PISTON BY MESSRS. MAXTON AND CO.

Fig. 221. represents a form of marine piston at one time manufactured largely by Messrs. Fawcett and Preston. It bears a considerable resemblance to Forrester's locomotive piston, sharing both in its merits and its defects. To enter into a detailed analysis of it would be superfluous, after having considered so much at length the general principles by which our judgment has been regulated.

Fig. 221.



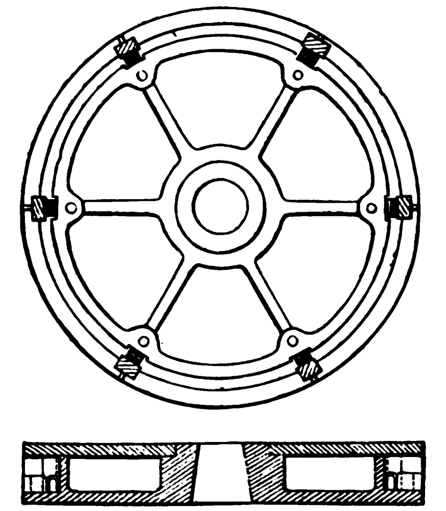
Scale ¼ inch=1 foot.

PISTON BY MESSRS. FAWCETT AND PRESTON.

Fig. 222. is the form of piston adopted by Mr. Robert Napier in many of his vessels, being similar to that used in the Halifax line of packets. The peculiar shape of the blocks against which the springs press, instead of the usual V wedge, is one point of identity between this and that given in our plates of details of a marine engine.

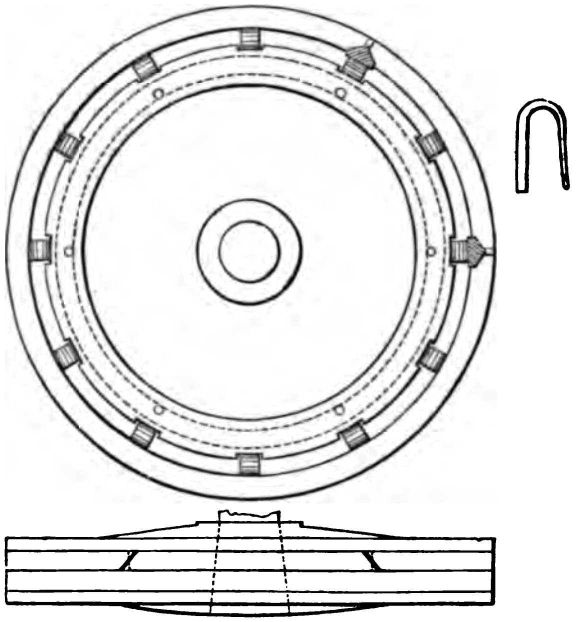
Fig. 223. represents the form of piston at present constructed by Mr. Robert Napier. Two rings, about 2¼ in. square (cylinder being 65 in. diameter), divided into two segments, the lengths of which may be in the proportion of 1 to 5, each ring being pressed out with a number of springs, generally made very stiff, and of little compass: the rings, in consequence, wear so rapidly, that we have known them to require to be eked with a considerable thickness of copper at the ends. We do not know the object of dividing the segments in the above proportion, unless it be to take out the rings without taking off the cross-head: in other respects a single break would be quite as efficient. The distinguishing feature of this piston lies in the cut on the outer circumference of the rings being made at a considerable angle with the perpendicular, while that on the inner side is vertical; an arrangement that we do not recollect to have met with before. The peculiar form of spring shown here, in an enlarged view, is, so far as we have observed, adopted almost exclusively by Mr. Napier.

Fig. 222.



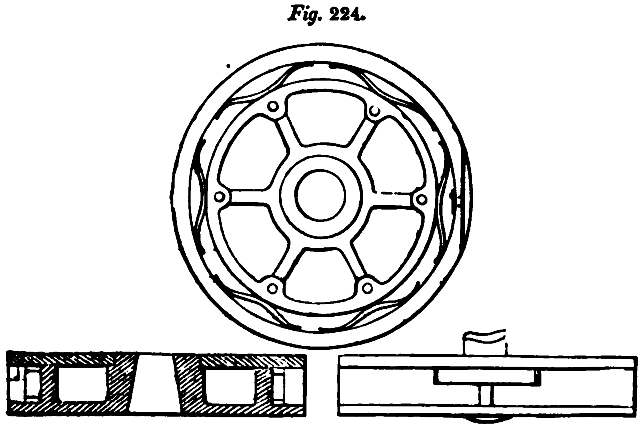
Scale ½ inch=1 foot.
PISTON BY R. NAPIER.

Fig. 223.



Scale ½ inch=1 foot.
PISTON BY R. NAPIER.

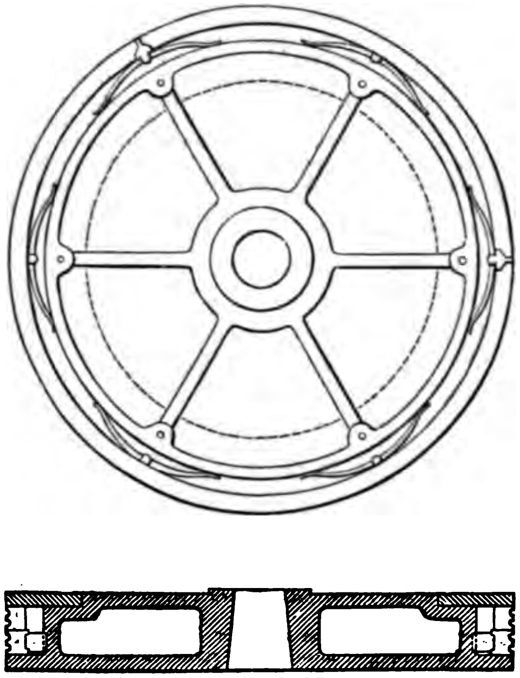
Fig. 224.



Scale ½ inch=1 foot.
PISTON BY MESSRS. SEAWARD.

Fig. 224. represents the species of packing-ring employed by the Messrs. Seaward. Only one packing-ring is used, about 3¾in. × 1¾in.; sprung in from a larger diameter, or hammered internally so as to have considerable elasticity. This ring is cut in only one place, and a piece, 8 in. or 9 in. in length, half the thickness, and about one-third the depth of the ring, is checked in on the upper side, in order to break bond; and at the back of the joint a block is placed, screwed to the one end of the ring and loose at the other, so as to prevent the steam from passing through the cut. In addition to the elasticity of the ring, it is pressed out by six elliptical springs. This is, on the whole, one of the best marine pistons we have met with. The ring, however, in wearing, deranges the joint between the ring and the small segment-piece. The joint opens at each end, so that the only contact comes to be at the central point, which is a defect.

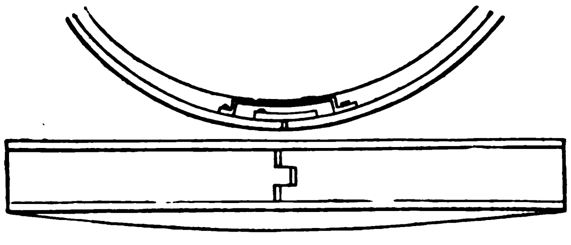
Fig. 225.



Scale ½ inch=1 foot.
PISTON OF DON JUAN STEAMER.

Fig. 225. shows plan and section of the piston of the "Don Juan's" engines (cylinder 68 in. diameter). There are two rings cut into two segments, the lesser being one-third the circumference, with V blocks at the joinings, and stiff elliptical springs.

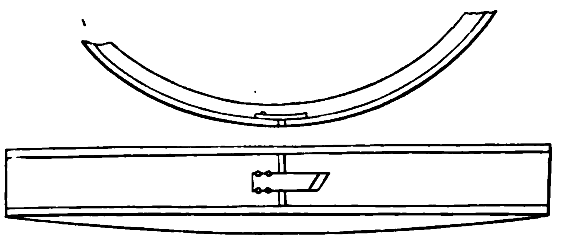
Fig. 226.



Scale ½ inch=1 foot.
PISTON OF WEST INDIA MAIL STEAMERS TRENT AND ISIS, BY MILLER, RAVENHILL, AND CO.

Fig. 226. shows the species of piston employed by Messrs. Miller, Ravenhill, and Co. The ring is turned the full size, measuring to the point of the tongue-piece, and squares are then cut out to allow the ends to come together, so that the tongue-piece is in one piece with the ring. The malleable iron bridle is for the purpose of expanding or contracting the ring, which is effected by driving in a cutter at the one end of the bridle or the other, whereby the ring is contracted or expanded. One end of the bridle is attached to the ring by a bolt, which slides in an oblong hole in the bridle; and if a cutter be driven between the bridle and one end of the piece ground on the back of the joint, the ring will be expanded; whereas, if driven at the opposite side, the ring will be drawn together.

Fig. 227.

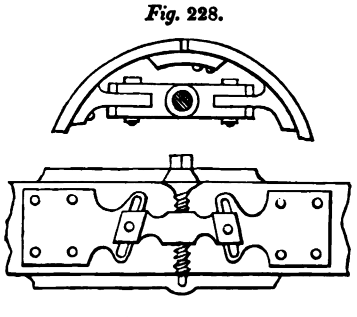


Scale ¼ inch=1 foot.

PISTON OF WEST INDIA MAIL STEAMERS THAMES AND MEDWAY, BY MAUDSLAY, SONS, AND FIELD.

Fig. 227. represents the marine-engine piston of Messrs. Maudslay and Field. Here the tongue-piece is not cast in one with the ring, but is put in with pins; and the slot is on the incline, to prevent a rut in the cylinder. The tongue-pieces, of this and the preceding variety, are of course ground in, a piece being ground on the back to prevent the steam from passing. This species of piston ring is probably among the best yet introduced in practice; yet, in the West India mail steam vessels, it was found that the pistons were not tight until springs had been introduced to press out the rings. The elasticity of these rings must therefore be reckoned insufficient; and it is a very common fault of metallic pistons that the springs are made too weak. We have often known them to be too weak, but never in any one instance knew them to be too strong.

Fig. 228.



Scale 1 inch=1 foot.

BRIDLE FOR MAUDSLAY AND CO.'S PISTON VALVE.

Fig. 228. represents the piston used for Messrs. Maudslay's cylindrical slide-valves. By raising or lowering the screw, it will be evident that the rings are compressed or expanded. A flat place is of course cast in the body of the piston to leave room for the bridle.

The pistons of Messrs. Scott and Sinclair consist of a number of segments pressed out by V blocks acted on by a continuous ring spring. Messrs. Caird's are similar, but the blocks are flat, and the springs are separate, as may be seen in the plates of the details of the Clyde, Tweed, Tay, and Teviot steamers. Messrs. Blythe's consist of two eccentric rings, one above the other, without springs or packing. Messrs. Fairbairn and Co. have made several with a double tier of eccentric rings, having eccentric rings again within these, so that the interior of the inner ring is concentric with the exterior of the outer. The space behind the inner rings is also packed with hemp. This variety of piston is troublesome to keep in good repair.

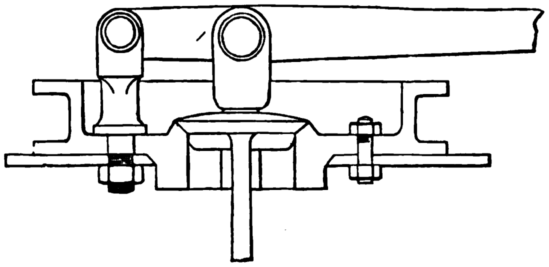
In the pistons of oscillating engines, it is necessary to take precautions against any compression of the packing-ring by the weight of the piston during the inclination of the cylinder. The method pursued by Messrs. Penn is to pack the space between the metallic ring and the piston with hemp. It might be a good way to force out the ring by means of a V block placed on one side of the piston, in the line of the trunnion, a steady pin being inserted in the piston on the opposite side, with a corresponding oblong hole in the packing-ring, so as to prevent the packing-ring from turning round at the same time that it was permitted to expand. Messrs. Penn make use of a single ring and tongue piece with the block behind recessed, so as not to interfere with the hemp packing. The upper side of the ring, too, is sharpened off to an edge.

VALVES.

We now come to the subject of valves, and here we have nearly as great variety as under the head of pistons. The function of a valve is to open or close a passage, and all the varieties are divisible into the genera of lifting and sliding valves. Sliding-valves are generally employed to admit the steam alternately above and below the pistons of engines, except in the case of pumping-engines, and there lifting or spindle valves are usually employed. Safety-valves are always spindle-valves, though a slide-valve, opened by the rise of a column of water or mercury, has been proposed as a safety-valve. The valves of pumps are generally spindle, flap, or ball valves, but are slide-valves sometimes. A cock is to be regarded as a circular sliding-valve. The diameter of the spindle of spindle-valves is usually made about one eighth of the diameter of the valves: in small valves the proportion is greater.

Safety-valves.—We have in page 86. given a theoretical investigation of the size of orifice requisite for safety-valves; but, as is there stated, much larger orifices are employed in practice. A common proportion is a circular inch of orifice per 1¼ horse power, or ·8 of a circular inch per horse power. In marine engines safety-valves are usually lifted by a lever, which presses up the spindle from underneath, and the weights are either wholly or partially hung from the spindle. The spindles are sometimes guided by means of an iron bar, which passes across the steam-chest; but this is not a commendable practice, as explosions have occurred from the jamming of the spindles in the guide, in consequence of an alteration of shape in the steam-chest when the pressure came on. *Fig.* 229. represents the safety-valve of a locomotive engine, which is of the steelyard kind, and the end of the lever is kept down by a spring.

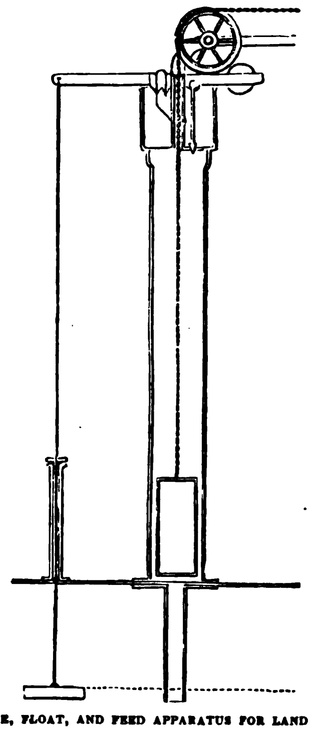
Fig. 229.



SAFETY VALVE OF LOCOMOTIVE BOILER.

Boiler explosions sometimes arise from the adhesion of the safety-valve to its seat, and numerous plans have been devised, and some of them of considerable ingenuity, for obviating this source of danger. The ordinary method of feeding land boilers by a head of water may rank among these contrivances: it is shown in *fig.* 230. A float, which is usually made of stone or iron, is so balanced, by means of a counterweight, that it rises or falls with the fluctuations of the water level, and in so doing opens or closes a valve in a small cistern, at the top of a stand-pipe set on top of the boiler, thereby maintaining the water at the right level. The stand-pipe is of sufficient diameter to receive a float connected with a chain proceeding to the damper; and as the water is forced up in the stand-pipe to a height corresponding to the elasticity of the steam, the float in the stand-pipe will rise and fall with the varying pressure, thereby adjusting the vehemence of

Fig. 230.

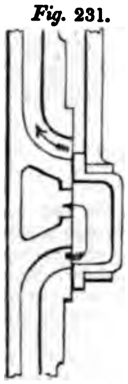


STAND PIPE, FLOAT, AND FEED APPARATUS FOR LAND BOILERS.

the draught to the wants of the engine. If the pressure becomes very high, the water will be forced out of the boiler through the feeding-valve. This valve, however, is usually made too small to be capable of answering as a safety-valve, but it gives intimation of danger. In steam vessels an upright pipe has been recommended to be applied to the top of the boiler, of sufficient capacity to give free exit to the steam, and descending beneath the water level, so as to be under ordinary circumstances filled with water. When the steam becomes too high, the water is forced up this pipe, and proceeds into the chimney by a branch-pipe provided for the purpose. If the pressure be not speedily relieved, the whole of the water above the mouth of the pipe will leave the boiler, and then the steam will rush out. Another plan consists in the application of a vessel at the end of a lever, to receive the water which flows over from the upright pipe, and this vessel of water is so arranged that its weight opens the safety-valve. In some combinations a column of quicksilver is employed, instead of a column of water; but it has been found that the quicksilver is gradually dissipated by the action of the steam. A large steam-gauge is recommended by some persons as an effectual safeguard against explosion, in the event of an adhesion of the safety-valve; but for all ordinary pressures we think the column of water already described will be found to be a preferable expedient.

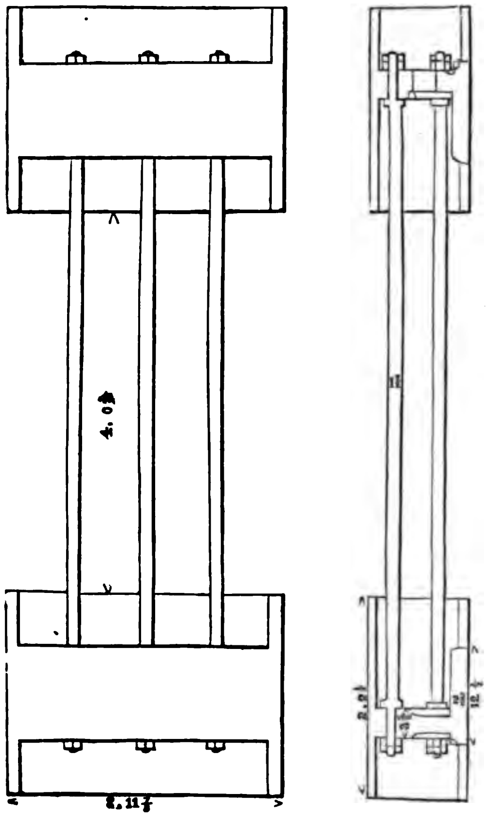
Slide-valves. — There are three principal varieties of slide-valves — the long D, the short D, and the three ported. The long D is represented among the details of the engines of the Clyde, Tweed, Tay, and Teviot steamers, and the three-ported valve is shown in the plates we have given of locomotive engines; but we here again represent it in *fig.* 231. This valve consists of a box set over a central port, and moved alternately over ports set on each side of the central port, so as to establish a communication between the central and side ports alternately. The central port is the escape port: the steam passes in the direction of the arrows, and when exhaustion is being performed by one port, steam is being admitted by the other. This species of valve is used very extensively in high-pressure engines, and almost universally in locomotives. It is very simple; and by leaving the face of the cylinder when the pressure within the cylinder exceeds the pressure in the valve-casing, it enables the water to escape when the engine primes: but it occasions a considerable waste of steam if the ports and passages are large; and if they are not large, a considerable loss of power arises from the extra-resistance experienced by the piston.

Fig. 231.



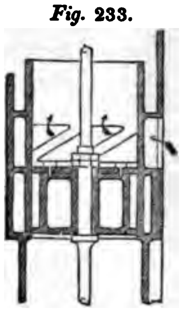
The long D valve has always been in much favour with engineers, though, as we think, without sufficient reason. The short D valve, is in our judgment, preferable, and we give in *fig.* 232, an excellent specimen of this species of valve — the valve of the steamer Don Juan. Some short D valves have only one rod to connect the ends, and others have two; but three are preferable, as they give greater stiffness than is otherwise attainable. It is expedient to zinc the connecting-rods, as in the wake of the ports they frequently get wasted rapidly away by the steam.

Fig. 232.



SLIDE-VALVE OF DON JUAN STEAMER.

Fig. 233.

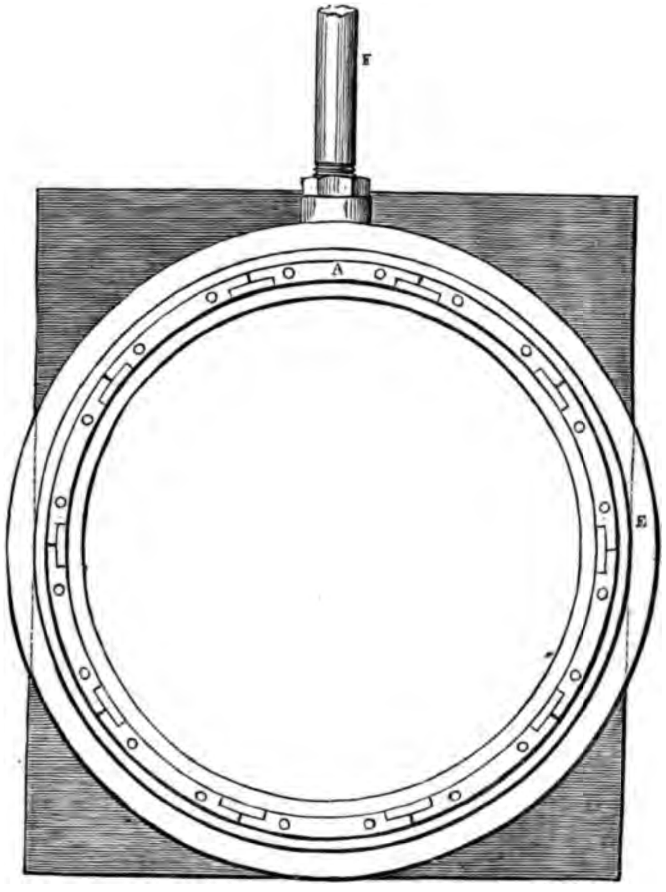


PISTON VALVE.

The piston-valve with skewed ports is represented in *fig.* 233. This species of valve is, in our judgment, preferable to the D in many respects. It is more easily worked, admits of metallic packing, and is not liable to have its form altered by twisting. Messrs. Miller, Ravenhill, and Co., have adopted this species of valve in their oscillating engines of the largest size, but in this instance its operation has not been satisfactory.

In working large engines considerable difficulty is experienced in handling the valves, from the weight and the pressure of the steam forcing the valve against the face of the cylinder. Various schemes have been adopted to obviate this disadvantage. In some cases a small engine has been used to work the valves at starting, and another plan has been to balance the valves by the opposing pressure of the steam. One of these balance valves is represented in figures 234, 235, and 236. It is a slide-valve, and has no hemp packing as is usual, but is kept tight by means of a metallic packing-ring, divided into segments which are pressed against the inner side of the valve-chest back by spiral springs and steam pressure. Some inconvenience might be anticipated from the circumstance of the rubbing surface of the packing-ring at the sides of the valve being greater than at the ends: but we understand from Messrs. Rennie, by whom this valve was devised, that its performance has been found satisfactory.

Fig. 234.

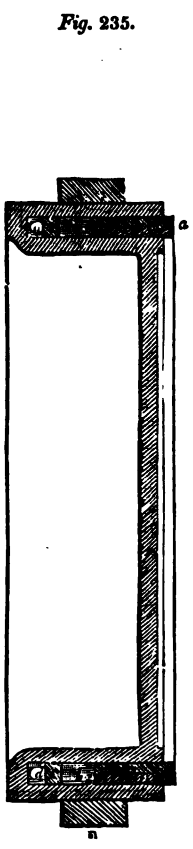


Back View.

EQUILIBRIUM SLIDE-VALVE, BY MESSRS. RENNIE.

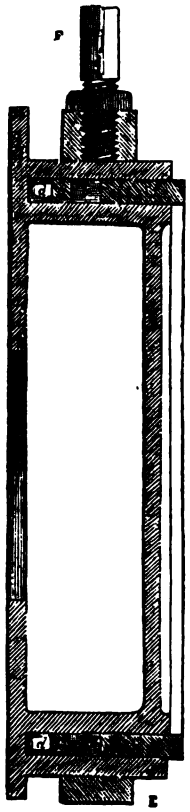
a a a is a brass ring divided into segments, as shown in the plan, the object being to allow the ring to accommodate itself to any slight curve that may be caused by the pressure of steam on the valve-box back or cover. *b b b b* is a space containing about three layers of well-plaited square gasket. *c c c c* is a brass ring in one piece fitted loosely into the groove, having on one side of it a number of small steel pegs, *d d d d*, on which is placed spiral springs. These springs force the ring, and by it the hemp packing is pressed hard against the brass segments, causing them to slide steam-tight against the valve-box cover, the pressure being further regulated by a communication made between the space in which the spiral springs work, and the steam in the valve-box.

Fig. 235.



Transverse Section.

Fig 236.



Perpendicular Section.

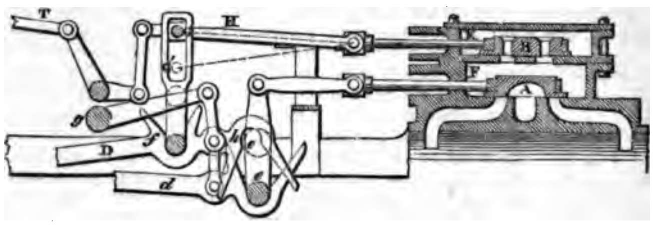
EQUILIBRIUM SLIDE-VALVE, BY MESSRS. RENNIE.

A communication is made between the condenser and the space within the brass ring *a a a* in the valve-box cover, and the condenser, regulated by a cock, so that when the engineer is handling the engine he can cause a vacuum at the back of the slides. E E E is a wrought iron hoop bound to fit the turned part of the valve, which slides freely in it, uninfluenced by the valve-rod F F.

The valve employed by Messrs. Penn in the most recent of their oscillating-engines, is substantially the same with that just represented. The ring, however, is in a single piece, and is tightened against the back plate by means of another ring, armed with four lugs, lying beneath the packing-ring. Between this ring and the packing-ring hemp packing is interposed, and the lower ring is raised up by unscrewing out of bosses on the valve, four bolts passing through the lugs. These bolts may be unscrewed, and the packing tightened, by removing four plugs in the back of the valve-casing. By this method of arrangement it is not necessary to make the back of the casing removable, but merely to plane and fit the back to the rings before the parts are put together. The back plate which forms the cover of the casing is scraped as carefully as the valve and cylinder faces, but only as much of the back plate is thus fitted as the ring comes into contact with during the travel of the slide, and the fitted portion is cast a little higher than the other portions.

Expansion-Valves. — Slide-valves are the most satisfactory species of expansion-valve; but spindle-valves are the simplest, and they are the most frequently employed. Most of the spindle expansion-valves are of the double beat or equilibrium kind, such as are used in the Cornish engines, and the nature of which has been already explained in page 173. In the plates of details of the West India mail engines a specimen of this species of valve is given, with appropriate cams to be applied to the shaft for working it by. In Mandslay's portable engine the cam is moved on the shaft by the governor, and the speed of the engine regulates the point at which the steam is cut off. The form of the cam is a sort of twisted elliptical cylinder, so to speak, against the exterior surface of which a pulley fixed on the end of a lever, presses, and by the motion thus derived opens the valve. This species of cam was employed in the Berenice steam vessel, by Mr. Robert Napier, but the valve was in that case a slide-valve, consisting of a plate interposed between the face of the valve and the face of the cylinder.

Fig. 237.

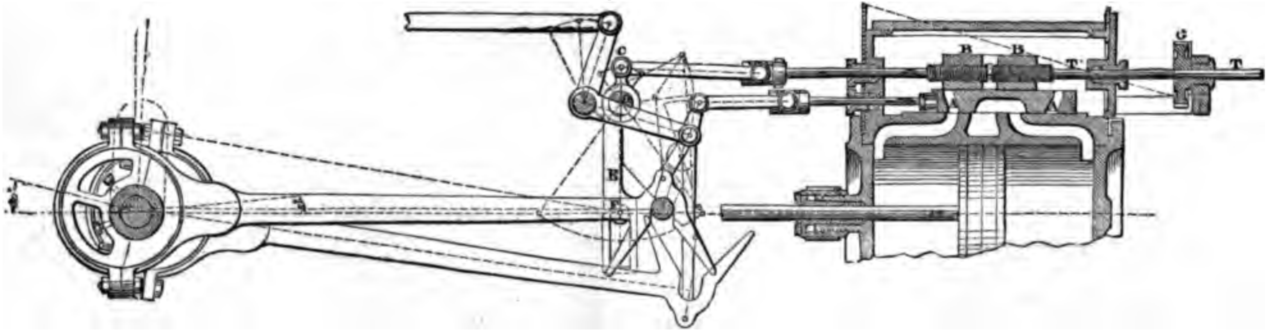


GONZENBACH'S EXPANSION VALVE.

Fig. 237 represents the variable expansion gear of Gonzenbach. It consists of an ordinary short slide-valve and casing, with ports in the back, upon which another slide-valve and casing are imposed. The ordinary valve is worked in the usual manner; but the travel of the supplementary valve may be lengthened or shortened, so as to cut off the steam at any part of the stroke. A is the common valve, and F the valve-chest; B is the supplementary valve, which is a solid block with two perforations, which, when opposite the ports in the cover F, admit steam from the supplementary valve-chest K. The starting-handle is connected with the shaft *g*, upon which a lever is fixed, and so connected by links with the extremities of the eccentric rods D and *d*, that when one eccentric gab is in gear with the pin *e*′, upon the valve-lever, the other shall be disengaged. In the figure the engine is in gear for going a-head, and the reversing eccentric rod D is disengaged from the ordinary valve, and in gear with the supplementary valve, by means of a second gab *f*, which receives a pin upon the expansion-valve lever G′. In this lever there is a long slot, in which a pin G, fixed on the valve link H, may be moved to a greater or less distance from the centre of the expansion-valve shaft, by means of the handle T; and the effective length of the valve-lever being thus varied, the travel of the valve receives a corresponding variation. The expansion-valve thus receives the reversing motion while the slide-valve is receiving the forward motion.

Mr. Cabrey has used a mode of obtaining expansive action, which bears some resemblance to Gonzenbach's plan, but dispensing with a second valve. It consists simply in making the eccentric rod terminate in a pin working in a slotted valve-lever, which has a gab similar to the ordinary eccentric gab. The throw of the valve will therefore depend upon the position of the eccentric pin in the slot; for the effective length of the lever will vary with the distance of the pin from the centre of the valve shaft; and the nearer it approaches that, the smaller will the throw become. By this means expansive working can be obtained with no cover on the valve, but it has the great defect of not opening the ports at the proper time. This may be obviated by increasing the lead of the eccentrics with the degree of expansion; which has been done by Mr. Fenton, by means of spiral feathers upon the crank shaft fitting into corresponding grooves in the eccentric, which, when shifted by a lever along the shaft, will necessarily

Fig. 238.



MAYER'S EXPANSION GEAR.

be turned round upon it, and thus give the required lead. *Fig.* 238. represents the variable expansive gear of Mayer. It consists of an ordinary valve, with the addition of perforations through the top and bottom faces, each of which are covered by a supplementary valve upon the back of the first, consisting of two solid blocks, into which a valve rod is screwed, having a right-handed screw where it penetrates the one block, and a left-handed screw where it penetrates the other; so that the blocks will be set closer or further apart, according to the direction in which the rod is turned. The ordinary valve receives its motion in the usual way, and the expansion-valve is moved by means of a pin attached to the piston-rod, which works in a slotted lever, to which the expansion-valve rod is attached. The motion of the two valves is, therefore, at right angles, and the expansion-valve is about one-fourth of a revolution in advance of the steam-valve. In the figure, A is the steam-valve, BB the expansion-valve, TT the valve rod, with right and left handed screw; G a wheel attached to the valve rod, over which a pitch chain passes, by means of which the valve rod is turned, and the blocks are altered so as to give the requisite amount of expansion; D is the valve shaft, and CE the valve lever; F is the pin attached to the piston rod. In all cases in which the motion of the expansion-valve is the same as that of the piston, the slide-valve must be provided with lap.

The expansion of the American engines is, as shown in the engine figured in page 190, generally a disk turning upon an axis like a throttle-valve, but so made as to be capable of being turned completely round in the pipe. The expansion-valve of the Don Juan was of this description, and was worked from a pin in a pinion, which made two turns for each revolution of the engine. In Mr. James Whitelaw's expansion-valve the valve shaft is cranked slightly, so as to enable the end of a double-ended lever to be in the centre line of the shaft, the centre of this lever being supported by a pin passing through the valve levers, and the expansion-valve, which consists of a plate placed between the valve and cylinder faces, is hung from the other extremity. So long as the end of the lever which is situated in the central line of the valve shaft, is preserved stationary, the expansion-valve has the same motion as the other valve, or is relatively at rest, so that no expansion then takes place; but if the end referred to of the lever be moved, as is done by means of a suitable cam upon the shaft, expansion answerable to the degree of motion is then accomplished. Some expansion-valves are gridiron valves, or valves consisting of a great number of ports instead of one, whereby the extent of travel necessary for their action is diminished. Mr. Bourne has introduced into some steam vessels a species of expansion-valve which cuts off the steam close to the valve face, so as to prevent expansion in the valve-casing, and is easily applicable to existing engines. It consists of two plates, moving between the valve tails of the D valve, and shutting up against the lap. These plates are connected together by a rod, and motion is given to them by means of a suitable cam or tappet: for moderate rates of expansion the motion given by a tumbler will suffice. In engines with a considerable amount of lap upon the valve, the amount of expansion will be increased by partially closing the throttle-valve, and in such cases the use of an expansion-valve in the steam-pipe cannot be productive of much benefit. This effect is traceable to the quicker motion of the piston in the cylinder as it approaches the centre of the stroke; for a size of orifice that will admit steam enough to keep up the pressure at the beginning of the stroke, when the motion is very slow, will not do so when the motion quickens, and the pressure necessarily subsides within the cylinder. If, however, there be no lap upon the valve, the pressure within the cylinder will rise towards the end of the stroke, when the motion again becomes slow; but if there be lap upon the valve sufficient to prevent the steam from entering towards the latter part of the stroke, the steam may be very largely expanded in the cylinder by throttling in the steam pipe. To make the action satisfactory, however, the throttling of the steam should take place close to the steam port; and one of Mr. Bourne's arrangements consists of a moveable plate covering holes upon the steam side of the valve, through which holes the steam finds ingress into the cylinder. These moveable plates are not made to travel at every stroke of the valve, as in the case of common expansion valves, but are moved by means of a rod passing through a hollow valve, spindle or otherwise, merely, whenever the rate of expansion requires to be changed; and the extent to which the steam orifices are open determines the extent of the expansion. The valve is made with sufficient lap to cut off the steam when about two thirds of the stroke have been performed, and with these proportions, and with the steam orifices very much contracted, the expansion begins very near the beginning of the stroke, and continues down uninterruptedly to its close. This species of expansion valve appears to be the best for locomotive engines, and for all engines, indeed, travelling at a quick speed, to which species of engine the spindle expansion valves are inapplicable. The moveable plates may obviously be used as a throttle valve, and the steam, by their instrumentality, may be completely shut off without throwing the engine out of gear. In all cases in which there is much lap upon the valve, it is expedient to make the throw of the valve more than twice the depth of the ports; as the orifice of the eduction passage will otherwise be too much contracted.

CHAPTER XI.

DETAILS OF ENGINES.

THE PUMPING-ENGINE.

In a pamphlet printed by Messrs. Boulton and Watt, for the use of their servants, sometime between 1782 and 1785, we have some excellent practical directions respecting the construction and management of pumping-engines, the greater part of which are applicable to the circumstances of the present time. This pamphlet is now very scarce; but we have been favoured by Messrs. Boulton and Watt with the use of a copy, and propose here to insert the most valuable part of its contents. Mr. Watt's hand is visible enough in this production, and the highest praise we can give to it is to say that it is worthy of its author. Under the head of general directions we have the following: —

"Having fixed upon the proper situation of the pump in the pit, from its centre measure out the distance to the centre of the cylinder, that is the length of the working-beam, or great lever, and the half breadth of each of the great chains, as shown by the drawing. Then from the centre of the cylinder set off all the other dimensions of the house, including the thickness of the walls, and dig out the whole ground included (to the depth of the bottom of the cellar) so that the bottom of the cylinder may stand on a level with the natural ground of the place, or lower, if convenient, for the less height the house has above ground, so much the firmer will it be. The foundations of the walls must be laid at least two feet lower than the bottom of the cellar, unless the foundation be firm rock, and care must be taken to leave a small open drain into the pit quite through the lowest part of the foundation of the lever wall, to let off any water that may accidentally be spilt in the engine-house, or may naturally come into the cellar. If the foundation at that depth does not prove good, you must either go down to a better, if in your reach, or make it good by a platform of wood or piles, or both.

"The foundation of the lever wall must be carried down lower than the bottom of the space left under the condenser cistern (to get at the screws which fix the condenser), and two short walls must be built to carry the beams under the condenser cistern. Two other slight walls should be built, one on each side, at a little distance from that cistern, to keep the earth from it, which would otherwise cause it to rot.

"Within the house, low walls must be firmly built to carry the lower cylinder beams, so as to leave sufficient room to come at the holding-down screws, as shown in the drawing, and the ends of these beams must also be lodged in the wall, but the platform is not to be built on them until the house is otherwise finished.

"The lever wall must be built in the firmest manner, and run solid, course by course, with thin lime mortar, and care must be taken that the lime has not been long slacked. If the house be built of stone, let the stones be long and large, and let many headers be laid through the wall; it should also be a rule, that every stone be laid on the broadest bed it has, and never set on its edge. A course or two above the lintel of the door which leads to the condenser, build in the wall two parallel, flat, thin bars of iron equally distant from each other, and from the outside and inside of the wall, and reaching the whole breadth of the lever wall. About a foot higher in the wall, lay at every four feet of the breadth of the front, other bars of the same kind at right angles to the former course, and reaching quite through the thickness of the wall, and at each front corner lay a long bar, in the middle of the side walls, and reaching quite through the front wall. If these bars are 10 or 12 feet long, it will be sufficient. When the house is built up nearly to the bottom of the opening under the great beam, another double course of bars are to be built in, as has been directed.

"At the level of the upper cylinder beams, holes must be left in the walls for their ends, with room to move them laterally, so that the cylinder may be got in, and smaller holes must be left quite through the walls, for the introduction of iron bars; which being firmly fastened to the cylinder beams at one end, and screwed at the other or outer end, will serve by their going through both the front and back walls, to bind the house more firmly together.

"The spring beams, or iron bars fastened firmly to them, must reach quite through the back wall, and be keyed or screwed up tight, and they must be firmly fastened to the lever wall on each side, either by iron bars, firm pieces of wood, or long strong stones reaching far back into the wall; they must also be bedded solidly, and the sides of the opening built in the firmest manner with wood or stone. The spring beams must always be laid eight inches on each side distant from the working beam, to give room for the side arches.

"The house being finished, a wooden platform of 2½ inch plank, is to be laid on the lower cylinder beams, and the centre of the cylinder being accurately marked on it, four holes are to be bored through the cylinder beams, for the holding-down screws, and four boxes, about seven or eight inches square, and as long as the stone platform is to be deep, are to be placed perpendicularly over them. Then the stone or brick platform is to be built up to the level of the cylinder's bottom, as shown in the drawing; it must be composed of the heaviest materials which can readily and cheaply be procured. A very solid pillar of stone or brick work, laid in the best lime mortar, must be carried up directly under the cylinder, and must be, at least, of the diameter of the outside of the flanches; the rest of the platform may be filled up with the heavy materials, bedded solidly in a mortar of clay and sand, and well beat into their places, so as never to settle or yield."

We next have some excellent remarks upon the construction of boilers, and upon boiler-setting: —

"In making the boiler you should use rivets between five eighths and three fourths inch diameter. In the bottom and sides the heads of the rivets should be large and placed next the fire, or on the outside, and in the boiler top the heads should be on the inside. The rivets should be placed at two inches distant from the centre of one rivet to the centre of the other, and their centres should be about one inch distant from the edge of the plate. The edges of the plates should be evenly cut to a line, both outside and inside. It is impossible to make a boiler top truly tight which is done otherwise. After the boiler is all put together, the edges of the plates should be thickened up, and made close by a blunt chisel about a quarter inch thick in the edge impelled by a hammer of three or more pounds weight, one man holding and moving the chisel gradually, while another strikes. All the joints above water should be wetted with a solution of sal amoniac in water, or rather in urine, which, by rusting them, will help to make them steam tight. After the boiler is set, it may be dried by a small fire under it, and every joint and rivet above water painted over with thin putty, made with whiting and linseed oil, applied with a brush. A gentle fire must be continued until the putty becomes quite hard, so as scarcely to be capable of being scratched off by the thumb nail, but care must be taken not to burn the putty, nor to leave off fire until it become dry.

"In building the brick-work of the boiler-setting, no lime must be used where the fire or flame comes, but a mortar made of loam or sand and clay; but lime mortar should be used towards the outside. Pieces of old cart tire, or other such like pieces of iron, may be laid under the chime of the boiler, between it and the bricks, which will prevent its being so soon burnt out there. The brick-work which covers the boiler top should be laid in the best lime, which will not hurt it there, but will preserve it; the mortar should be used thin, and the boiler top well plastered with it, which will conduce greatly to tightness, if done some time before the engine be set to work. If your lime be not of that species which stands water, it will be well to mix some Dutch or Italian terrass, or pan scratch from the salt works with it, but in any case the lime should be newly slacked. In carrying up the brick-work round the flues, long pieces of rolled iron should be built in two or three courses to prevent the brick-work from splitting. Four holes at convenient places should be made into the flues, large enough to admit a boy to go in to clean them. One of them may be over the fire door, and another right behind the damper in the back side of the chimney. This last may be as high as the flues themselves are. These holes, when not in use, are to be built up with nine-inch brick-work, and made perfectly air tight. Immediately above the brick-work of the boiler-setting, a hole must be left in the chimney on the side next the boiler. This hole must be as wide as the chimney, and one foot or 18 inches high, and must have a sliding door fitted to it, to open it more or less at pleasure; the use of it is to moderate the draught of the chimney, and to prevent the flame being drawn up it before it has acted sufficiently on the boiler. A groove must be left in the brick-work for the damper to move up and down in easily, which should fit flat to the face of it. The damper may be made to move easily up and down by means of a beam or a wheel, with a counterpoise equal to the weight of the damper. The best form of a fire door is two feet long and one foot high, inside measure, to have two leaves made of boiler-plates hinged on the two sides, and over-lapping one another about an inch in the middle. The scantling of the frame may be three inches broad by two inches thick."

We have next some directions respecting the formation of a refrigeratory pond for the hot water. Throwing the water up into the air in the form of a jet to cool it was found to be detrimental, as it charged the water with air, which vitiated the vacuum: —

"If you have not land water that will naturally run into the condenser-cistern, you must make a pool somewhere in the neighbourhood to receive the water from the hot-water pump, and reserve it for supplying the boiler and condenser-cistern when the engine stands still on any occasion. This pool may be at least 40 feet long, and 20 feet wide, to hold 3 feet deep of water; and pipes or troughs must be laid from its bottom to the boiler, feed-pipe, and to the cistern. That at the feed-pipe must have a cock on purpose. It is only meant that this pool be simply dug in the earth and lined with turf, puddled, or otherwise made water-tight. If no ground within a reasonable distance be high enough for the water to run from the bottom of the pool into the boiler, then a pool may be made on lower ground, and a hand-pump fixed up to supply the boiler and cistern; but this ought to be avoided if possible."

Next come some directions for putting the engine together: —

"Having put the working-beam together, and fastened the gudgeon to it, rest it on the plummer blocks; but do not fasten these blocks until the cylinder is fixed.

"Level the top of the stone platform, and lay the outer bottom of the cylinder down in its place, truly level, and corresponding to the holding-down screw-boxes.

"Apply the inner bottom upon the outer one, and set its upper joint level, by wedging betwixt it and the outer bottom if it requires it: then cut out segments of pasteboard, such as is used for the boards of books (not such as is composed of paper pasted together); let these segments be of such thicknesses as the different parts of the joint may require (if it be more open in some places than in others). Soak these pasteboard segments in warm water until they become quite soft, then lay them upon boards to dry, and when quite dry put them into a flat pan with a quantity of drying linseed oil; warm the oil until the pasteboard ceases to emit bubbles of air, but take care not to heat the oil much hotter than boiling water, otherwise it will harden or burn the pasteboard. Anoint the segments on both sides with thin putty made with fine whiting and some of the linseed oil; let the whiting be very dry, otherwise it will be difficult to mix with the oil, and N. B. that white lead will not answer in place of it.

"You must, as much as you can, avoid using more than one thickness of pasteboard, and the segments should be a little broader than the flanch, with all the holes cut out by a chisel, but not quite so large as the holes in the iron. The segments should also be thinned at the ends where they overlap each other, so that they may form a circle of pasteboard of an uniform thickness.

"To pack the piston, take sixty common-sized white or untarred rope-yarns, and with them plait a gasket or flat rope, as close and firm as possible, tapering for 18 inches at each end, and long enough to go round the piston, and overlap for that length; coil this rope the thin way as hard as you can, lay it on an iron plate, and beat it with a sledge hammer until its breadth answers its place; put it in and beat it down with a wooden driver and a hand-mallet; pour some melted tallow all round; then pack in a layer of white oakum half an inch thick, then another rope, then more oakum, so that the whole packing may have the depth of about four inches, or only three inches if the engine be a small one. Cast segments of a circle of lead, about 12 inches long, 3 inches deep, and 1¼ inch thick, fitted to the circle of the piston, and cut down square at both ends; lay them round upon the packing as close as they can lie to one another without jamming, and screw down the piston springs upon them; the piston springs should be bent downwards at the end next the piston-rod, and a little mortoise should be cut in the cast-iron there, for the bent-down point of each of them to lodge in, which will prevent their coming forwards to touch the cylinder. Previous to the piston being put into the cylinder, the hollows among the crosses should be quite filled up with solid pieces of deal wood, put in radius fashion. The packing of the piston should be beat solid, but not too hard, otherwise it will create so great a friction as to hinder the easy going of the engine. Abundance of tallow should be allowed it, especially at first; the quantity required will be less as the cylinder grows smooth.

"The joints being all made, the regulator valves in their places, and their covers screwed on, but no water in the condenser cistern, admit steam, and when the cylinder and steam case are thoroughly warmed, screw up the nuts of all your screws, and caulk the pasteboard or oakum of such joints as may require it, with a caulking chisel, until you find that every thing about the cylinder is perfectly staunch; then pour three or four feet deep of water into the hot-water pump; stake down the injection and blowing valves, and also those on the air-pump lid; then let the steam into the condenser, which will show the defects or leaks, if there be any.

"Screw on the steam gauge to the steam case near the nozzle, and behind the engine-man's place; pour as much mercury into it as will half fill the open leg; put a float on it, broad at bottom, but very slender in the stem; cut the float or index off close to the end of the open tube, and fix a scale to it, reckoning every half inch the float rises equal to an augmentation of the elasticity of the steam, corresponding to the supporting of a column of mercury an inch high, because the surface has sunk as much in the one leg as it has risen in the other. Solder a small copper fosset-pipe, to fit the copper communicating tube of the barometer, into the eduction-pipe, 12 inches under the fosset of the blowing valve, and on the opposite side of the eduction-pipe; place the barometer in the door-way to the condenser on the further side from the plug-tree, so that the engine-man may see it when at his station; join the copper tube to it by pouring melted sealing-wax into the copper cup at top; fill the short leg of the barometer with mercury, within four or five inches of its top, and put a light float in it, long enough to reach to the top of its frame.

"Fill the condenser cistern, shut the lower regulator, and there being no steam in the cylinder, or its communication with the boiler being cut off, take off the bonnet or cover of the exhaustion regulator, shut that regulator, and work the air-pump by means of the brake. If then you find that air enters by the regulator, pour some water on it, and continue pumping until you have raised the barometer, i. e. sunk its float, to 27 or 28 inches; leave off pumping, and observe if the vacuum continues good, or is a long time in being destroyed, If it looses fast, seek for the leaks, which must be somewhere in the eduction-pipe, and will make a noise if touched with a wet hand (observe if the condenser moves by the pumping, and secure it). After having cured these leaks, you may try the tightness of the cylinder by staking the working-beam, so that the piston cannot descend; then taking the cover off the cylinder, open the exhaustion regulator, and shut the steam regulator; on beginning to pump, you will perceive if the piston be tight; if it is not, it may be beat a little, and some water being thrown upon it, and on the steam regulator, whatever air enters must be by leaks, which must be sought for and cured by screwing or caulking in oakum.

"N. B. A critical tightness in the piston cannot be obtained until the engine has gone a few days, without beating it too hard, to permit the engine to move easily. When you can detect no more leaks in this way, the steam must be admitted, and the same examination made as before.

"After the engine has been set a-going, and has gone a few hours, the holding-down screws should be screwed tight, and so from time to time as they become slack; and in like manner all the other screws about the cylinder or nozzles should be screwed up as they slacken, and the joints caulked and puttied where they require it.

We have next directions for working the engine: —

"To set the engine a-going, raise the steam until the index of the steam gauge comes to three inches on the scale; when the outer cylinder is fully warmed, and steam issues freely on opening the small valve at the bottom of the siphon or waste-pipe, which discharges the condensed water from the outer bottom, open all the regulators; the steam will then forcibly blow out the air or water contained in the eduction-pipe, by the blowing-valve, but cannot immediately take place if the air is in the cylinder itself; to get quit of it, after you have blown the engine a few minutes, shut the steam regulator; the cold water of the condenser cistern will condense some of the steam contained in the eduction-pipe, and its place will be supplied by some of the air from the cylinder; open the steam regulator and blow out that air; and repeat the operation until you judge the cylinder to be cleared of air; when that is the case, shut all the regulators, and observe if the barometer shows that there is any vacuum in the eduction-pipe; when the barometer gauge has sunk three inches, open the injection a very little, and shut it again immediately; if this produces any considerable degree of vacuum, open the exhaustion regulator a very little way, and the injection at the same time; if the engine does not commence its motion, it must be blown again, and the same operation repeated until it moves; if the engine be very lightly loaded, or if there is no water in the pumps, you must be very nimble and shut the exhaustion and top regulators, so soon as it begins to move quickly, otherwise it will make its stroke with great violence, and perhaps do some mischief. To prevent which, open the top and exhaustion regulators only a little way, and put pegs in the plug-tree, so that they may be sure to shut these regulators long before the piston comes to the bottom.

"If there is much unbalanced weight on the pump-end, you must also take care to put a peg in the ladder which guards the steam-regulator lever, so as to allow that regulator to open only a little way, and so to lessen the passage for the steam, when it enters to fill the cylinder, otherwise the rods, &c., at the pump-end may descend too fast and be prejudicial; if you find, after a few strokes, that the engine goes out too slow, the steam-regulator may be opened wider. In order to regulate the opening of the exhaustion regulator, you should have pieces of board, of various thicknesses, to put under the weight which pulls it open, by means of which it may be made to open more or less at pleasure, and the top regulator may be managed in the same manner.

"Should the engine work with two great violence, on account of its being underloaded, you may correct it by giving the top regulator a lesser opening, and shutting it at such a part of the stroke as will just give the piston sufficient force to come to the bottom. Whenever the top regulator is used, the exhaustion regulator should be thrown fully open every stroke, in order to give a free exit to the steam, on which a great part of the good effects of the top regulator depends.

"The engine should always be made to work full stroke, that is until the catch-pins come within half an inch of the springs on each end, which is easily managed by an attention to the pegs. Care must be taken that the piston rise high enough in the cylinder when the engine is at rest, to spill over into the perpendicular steam-pipe any water which may be condensed above it; for if any water remain there, or in any other part of the cylinder while it is working, it will very much increase the consumption of steam. When the engine is to be stopped, shut the injection and secure it; put a peg in the plug-tree to prevent the exhaustion regulator from opening, and take out the peg on the other side, so as to allow the steam regulator to open and to remain open; otherwise you may have a partial vacuum in the cylinder, and it may be filled with water from the injection or leakages, which is a troublesome accident. The top regulator should also be open while the engine stands.

"When an engine is in tolerable good order, it will bear to stand ten minutes, and go to work again without blowing afresh; and though it has stood two or three hours, if there has been any steam issuing from the boiler, and no air has been admitted into the cylinder, it will generally go off with once blowing for about a minute.

"If you find, after following the above directions, that the engine does not go to work, shut the exhaustion regulator, and give some injection; if it then makes no vacuum, it is likely there are air leaks about the eduction-pipe; if it does make a vacuum which remains but a short time, it may be owing either to air or water leaks; these may be distinguished by blowing as before, and shutting the lower regulator for about a minute, without giving any injection. If, upon opening it again, it throws out a good deal of water at the blowing-pipe before it blows steam, it is certain that it either has some leak in the condenser under water, or that the injection or blowing valve does not shut close; if they are found to shut close, every joint should be examined, and also the valve at the foot of the eduction-pipe.

"If, after blowing as before, you find that immediately on opening the exhaustion regulator, a quantity of air is thrown out at the blowing-valve, the leak is in the eduction-pipe somewhere between the surface of the water in the cistern and the nozzle. The particular place of these leaks may be found, by emptying the cistern of water, putting three or four feet deep of water into the hot-water pump, and staking down the blowing and injection valves with those on the air-pump lid; then, if steam be admitted into the eduction-pipe, it will come out at the leaks, and point them out. If not found out in this way, apply the brake to the air-pump, taking care first to put some water on its bucket, and then by working that pump by hand, you will probably, on an attentive examination, observe where air goes in, which may be known more distinctly by wetting the place suspected.

"If upon shutting the lower regulator and making a vacuum in the exhaustion pipe by pumping, or by injection, you find that vacuum continues good for a considerable time, then the fault does not lie in the eduction-pipe, but in the nozzle or joint of the cylinder bottom, where it must be sought for.

"In these examinations by pumping it is proper to take off the bonnet or cover of the exhaustion regulator, and to examine if air enters at that regulator; if it does, and only in small quantity, throw some water on the regulator while you are examining the eduction-pipe; and when the leak is suspected to be in the bottom joint of the cylinder, or in the lower nozzle, you must throw some water on the steam regulator, and also on the piston, then, by pumping and strict examination, you will soon find where the air enters. When you are examining the tightness of the piston by pumping, you must stake the beam, so that the piston may not descend.

"If in course of working you do not find the vacuum keep good, and the engine goes sluggishly, or stops and requires to be blown frequently, you must examine whether an uncommon quantity of air or water issues at the hot-water pump, or if any comes out at the valves on the air-pump lid; if the quantity of air is great, the engine has some air leak; and if the quantity of water be great, and is rather cooler than usual, it proceeds from a water leak in the condenser; if the quantity of water be great, and at the same time very hot, it proceeds from a bad piston, or from the steam regulator not shutting close.

"The engine will also go badly if the air-pump or water-pump buckets or clacks strip the water, that is, let it pass by them. You will know if this be the case with the water-pump bucket, by observing whether the water follows down after it at the return of the stroke, and leaves a part of the pump empty; if it does not, either the bucket strips the water, or the engine receives water in some way which it ought not.

"Attention ought to be given to feeding the boiler in a regular manner, that it may not be spoiled, nor steam wanted. When there is too much water in the boiler, the engine will not work regular, and if there is too little, the sides of the boiler will be burnt by the flame in the flues. If by accident it should at any time run a little too low, the feed should be augmented, so as to fill it gradually; for if you run in too much at once, you will check the steam, and stop the engine; but if it be run very low, stop the engine, open the puppet clack, and fill the boiler from the pool or reservoir, if you have one; otherwise fill it by working the air-pump, having first staked down the valves on its cover, and opened the injection-valve. In working the engine, the steam ought to be strong enough to make the index of the steam gauge stand half an inch high at least, otherwise air will enter at the joints of the boiler, &c., and spoil the vacuum, so as to cause a good deal of trouble to get quit of it again. Therefore if you perceive the steam gauge to be lower, stop the engine until it rises again. By a little attention, you will find the proper opening of the feeding-cock for any rate of working.

"Let all the coals employed to feed the fire be thoroughly watered just before they are thrown on, as that will prevent their being swept into the flues by the draught of the chimney.

"The fire should be kept of an equal thickness and free from open places or holes, which are extremely prejudicial, and should be filled up as soon as they appear; if the fire grows foul and wants air, by clinkers collecting on the bars, they must be got out with a poker, but the fire should be as little disturbed in that operation as possible, and the greatest care taken not to make any coals or coke fall through which are not thoroughly consumed; it is very common for a fourth of the whole coals to be wasted in this manner, by mere carelessness. When the fire is newly made, the damper should be raised a little, so as to let off the smoke freely, but should be let down to its proper place so soon as the smoke is gone off. The air door in the chimney should be always open more or less; it prevents the flame from being sucked up the chimney, and very considerably increases the effect of the coals. Once a month the boiler and flues ought to be cleaned, or oftener if the water be very subject to incrust the boiler. Every morning the ashes ought to be taken out, the engine-house swept clean, and a view taken of every part of the engine, to see that nothing be working out of its place, or want oiling. Particular attention ought to be paid to the bolts and cutters of the great chains and piston rod, so that none of them get loose.

"An engine, when in good order, ought to be capable of going so slow as one stroke in ten minutes, and so fast as ten strokes in one minute; and if it does not fulfil these conditions, somewhat is amiss that can be remedied.

"The hot water should issue of the heat of 96 degrees of Fahrenheit's thermometer, that is, blood warm, when the engine is in excellent order, and should never exceed the heat of 110 degrees, unless when the injection or cold water is hotter than 70 degrees, and in that case the vacuum will not be good.

"To make putty for making or repairing the joints:—Take whiting, or chalk finely powdered, dry it on an iron plate, or in a ladle, until all the moisture be exhaled; then mix it with raw linseed oil, and beat or grind it well, adding more oil or whiting, until it be of the consistence of thick paint, and perfectly free from lumps or inequalities.

"For some purposes, where the putty is wanted to dry and to be very sticky, use painter's drying oil, which is made by boiling the oil with a small quantity of litharge or red lead.

"Where the putty is wanted to continue always soft, mix about two ounces of butter or common salad oil with each pound or pint of the linseed oil. This soft putty is principally useful in the caulked joints of the eduction-pipe, above water.—N. B. White lead will not answer in place of the whiting.

"No wet cloths should be suffered to be laid on the cylinder, boiler, or steam-pipes, and every part containing steam should be guarded as much as possible from the influence of cold air or water.

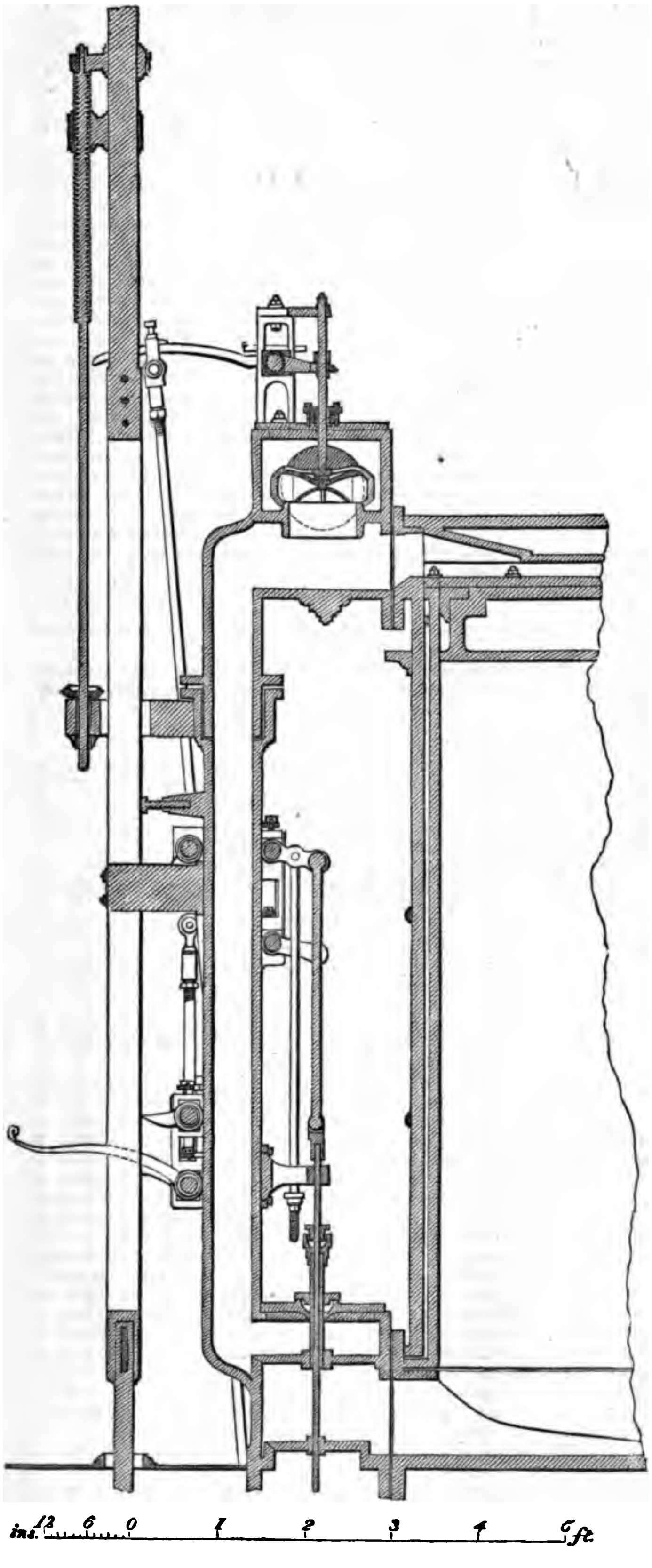
"The proper grease for the piston and cylinder stuffing-box is melted tallow, and for the chains, gudgeons, &c., common Spanish olive oil (called salad oil), which, for some uses, may be thickened by dissolving some tallow or butter in it by means of heat. Linseed oil should never be used as grease, as it dries and creates more friction than would have been without it. Hogs' lard, or train oil, if applied any where about the cylinder, or where it is hot, will thicken like linseed oil. When the oil or grease about the great chains, or any of the working parts, grows clotted or very thick, it should be scraped off before new grease is added.

"An improvement has lately been made in the covering boiler tops. The setting being built up to nine inches above the flues as usual, a course of horse or cow dung, three inches thick, and well beat, is applied to the boiler top; on the outside of that is laid some good lime mortar, about an inch in thickness, to which is applied a course of bricks flatwise, with their ends upwards; on the outside of that another course of bricks (also laid in good mortar) in the same position, but so as to break joint with the first course; in which manner the covering is carried on until the whole top is covered, taking care to leave an opening for the man-hole: every flanch may be thus covered; and when well done, it effectually makes the top steam tight, and also defends it from cold and rain, so that a boiler-house is not necessary. The mortar employed must be such as stands water."

Finally we have some "Additional Observations," supplementary to the foregoing, and which are as follow:—

"Instead of using painters' drying oil to make the joints with, take good raw or unboiled linseed oil, put it in an iron pot, place it over a gentle fire (out of doors, but protected from rain), let it be watched as it heats, as it is very liable to boil over; when it boils, make the fire more moderate, but continue to heat the oil, until upon dropping some of it upon a cold stone or piece of iron, you find it is, when cold, of the thickness of thick tar or treacle. The pasteboards for the joints are to be soaked in this oil warm, or painted over with it, and laid in a hot place to suck it up; and it is also to be used to make the putty with.

Fig. 239.



VALVE GEARING OF PUMPING-ENGINES AT CHELSEA WATER WORKS, BY MAUDSLAY, SONS, AND FIELD.

"The oakum with which the joints are caulked should be well smeared with the strong or thick boiled oil mentioned in these additional directions. If the under side of the pipe of the inner bottom does not fit close to the lower edge of the opening made for it in the outer bottom, that is to say, if the space left there for pasteboard or caulking be wider than one quarter of an inch, a piece of hammered iron an inch and a half broad must be forged of such thickness as to fill up the space, so as to make it tight by the help of a thickness of pasteboard above it, and another below it. Lead ought not to be used in these cases, as its expansion and contraction by heat and cold are too great. Instead of putting a prop from the nozzle to the ground, it is found better to put a balance beam off sideways under the floor, with a short upright having a flat end to take a broad bearing under the nozzle. The weight of the balance should not support more than two thirds of the weight of the nozzle.

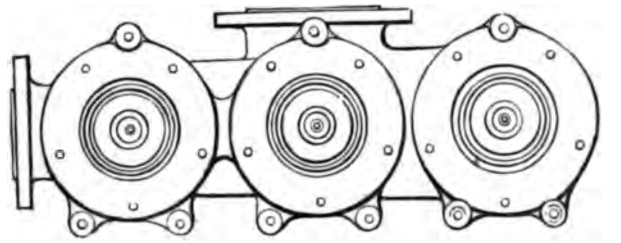
"Some people use a plaited rope to make the joint of the cylinder lid, which is a bad practice; for though a plaited rope may make a joint apparently steam tight, yet it has been found by experience, that such joints are not air tight; but when, by the working of the top regulator, a partial vacuum is produced in the upper part of the cylinder, they permit some air to enter imperceptibly, and without noise, which, of course, passes to the condenser, and by persons that are not aware of this circumstance, may be thought to enter at some air leak in another place. We therefore recommend that this joint be always made with pasteboard and putty; and that a strict attention be paid to the tightness of the stuffing-box, wherever the top regulator is used."

In the Cornish engines, as we have already mentioned, great diminution in the consumption of fuel has taken place since Mr. Watt's time, chiefly by the larger application of the principle of expansion. Taylor's 85 in. cylinder engine, erected at the United Mines in 1840, reached in 1842 an average duty of 107 millions of pounds raised 1 ft. high with a bushel of coals. In this engine the pressure of the steam is 40 lb., and it is cut off at one tenth or one twelfth of the stroke. To diminish the risk of fracture in engines using such high steam, Mr. Sims, of Redruth, has contrived a plan of double cylinder engine, which is much simpler in arrangement than those hitherto employed. The small cylinder here stands on top of the large one, and the same piston-rod passes through both. The same number of valves too that is used in common pumping-engines, suffices in this modification of the double cylinder plan.

The Cornish engines are always provided with a steam-jacket, but through this jacket the steam does not pass in its way to the cylinder. The steam jacket is kept filled with steam by a branch from the steam-pipe, which is about 4 in. in diameter in large engines. The clothing applied to the cylinder is very various: a common plan is to inclose the cylinder in a brick wall, leaving a space between them; to plaster the wall, and coat it with timber. The cylinder cover and cylinder bottom are usually made hollow, and filled with steam: they are then carefully coated with non-conducting materials.

The main beam of the engine usually consists of two cast-iron plates, bolted together, and armed with projecting horns to catch the spring beams, should the piston be disposed to strike the bottom of the cylinder. From the beam hangs the plug-rod, by which the valves are moved by means of some such arrangement as that shown in *fig.* 239. which differs in some respects from the Cornish form. The valves of the Cornish engine erected by Mr. Hosking at Vauxhall, and of which we have given a plate, are shown on a large scale in *figs.* 240. 241. and 242. These valves are of the equilibrium description. In 240. and 241. the valve to the left is the governor-valve, by the adjustment of which the flow of steam to the cylinder is regulated: the centre valve is the steam-valve, and the valve to the right is the equilibrium-valve. *Fig.* 242. represents the eduction-valve, which, it will be remarked, is larger than the others, so as to afford a free exit for the steam into the condenser. Three-quarters of a square inch per horse power is a common size for the steam-valve in rotative engines, furnished with spindle-valves; and a square inch and a quarter per horse power is a common size for the exhaustion-valve.

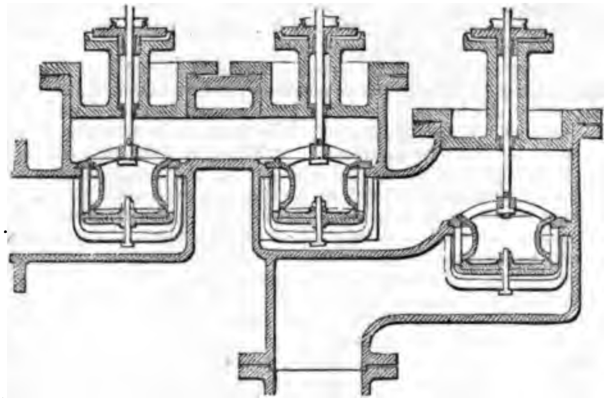
Fig. 240.



PLAN OF UPPER VALVE-CHEST OF HOSKING'S PUMPING-ENGINE, VAUXHALL WATER WORKS.

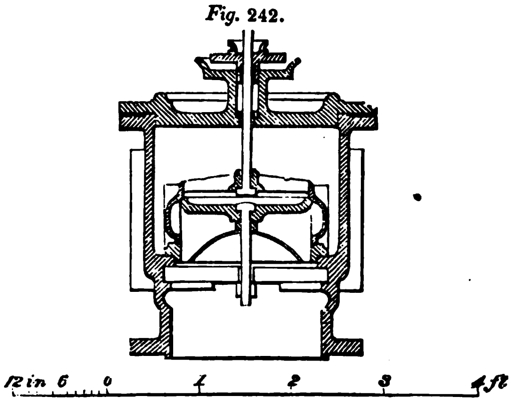
The plunger-pump is the pump universally used in the Cornish mines

Fig. 241.



SECTION OF UPPER VALVE-CHEST OF HOSKING'S PUMPING-ENGINE, VAUXHALL WATER WORKS.

Fig. 242.



SECTION OF EDUCTION-VALVE OF HOSKING'S PUMPING-ENGINE, VAUXHALL WATER WORKS.

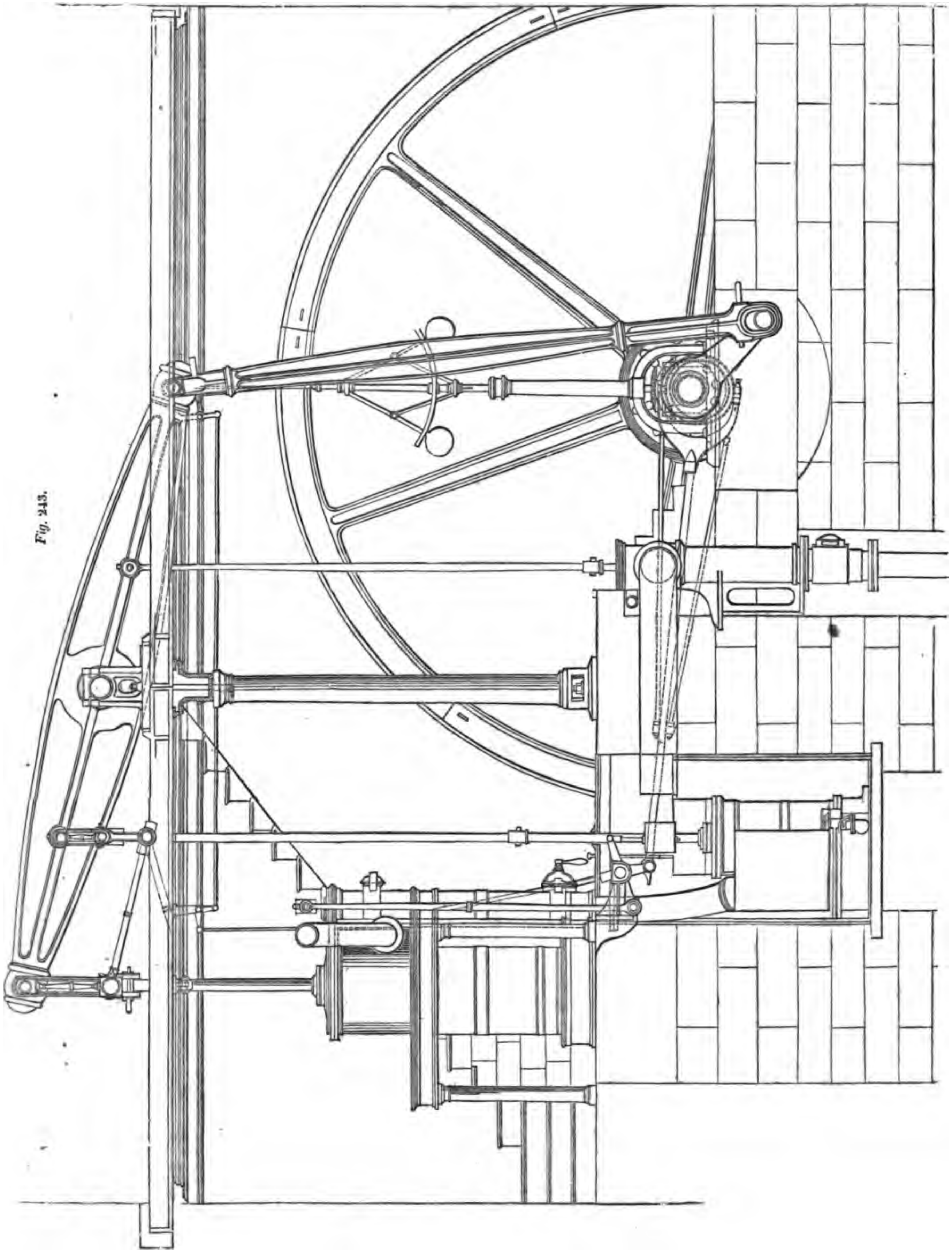
and it is much preferable to the lifting-pump, inasmuch as it can be packed afresh, or the packing may be tightened, with much greater facility than can be done in the case of a lifting-pump, while the friction is at the same time less. The shaft is divided into a succession of lifts, in which the water of the lowest lift is delivered to the pump next above it, and so on in succession until the water reaches the surface. The plunger-pump is used in all these lifts except the lowest, where the lifting-pump is used, with the view of obviating inconvenience, should the water from derangement in the machinery, or otherwise, rise so high in the mine as would make the valves and barrel of a forcing-pump inaccessible, and also on account of the facilities afforded by the lifting-pump in the drainage of the water as the mine is sunk deeper. The plunger-pump was invented about two centuries ago by Sir Samuel Morland, and was introduced into the Cornish engine by Murdoch. Its use obviates the necessity for as large a counterweight as would otherwise be necessary; for the force of the engine is expended in lifting the pump-rods, and the water is forced out by the weight of the pump-rods in their descent. The pump-rods of some of the engines, however, are too heavy for the engine to lift, and part of the weight has to be taken off by one lever or more, provided with counterbalance weights, placed either at the surface or in some convenient side excavation. The main pump-rod of Davy's engine at the Consolidated Mines, is one-third of a mile in length, and weighs 95 tons. The other rods weigh 40 tons, making a total weight of 135 tons, of which 39 only are wanted to balance the water in the pump, and the greater part of the remaining 96 is balanced by weighted levers, or as they are termed, "balance bobs". The main pump-rod is usually composed of balks of Memel timber, and at intervals down the sides of the shaft projecting pieces are bolted on, which catch upon suitable timbers let into the sides of the shaft, to prevent the rod from descending too far in the event of fracture above. The rod is guided at intervals by appropriate frames. There is something rather primitive in these expedients, and it appears to us not improbable that the whole of this cumbrous apparatus will hereafter be superseded by machinery operating by atmospheric pressure, whereby the pump-rods will be rendered superfluous, or else by the centrifugal pump; and a small engine, working at a quick speed, will suffice for working such an apparatus.

We have already given, in our remarks upon the subject of boilers, the chief results of the Cornish practice as regards the economisation of fuel. Into that question we need not again enter, but may here give the results ascertained by Mr. Enys of the operation of some of the principal Cornish engines.

Table of Observations upon Ten Cornish Engines.

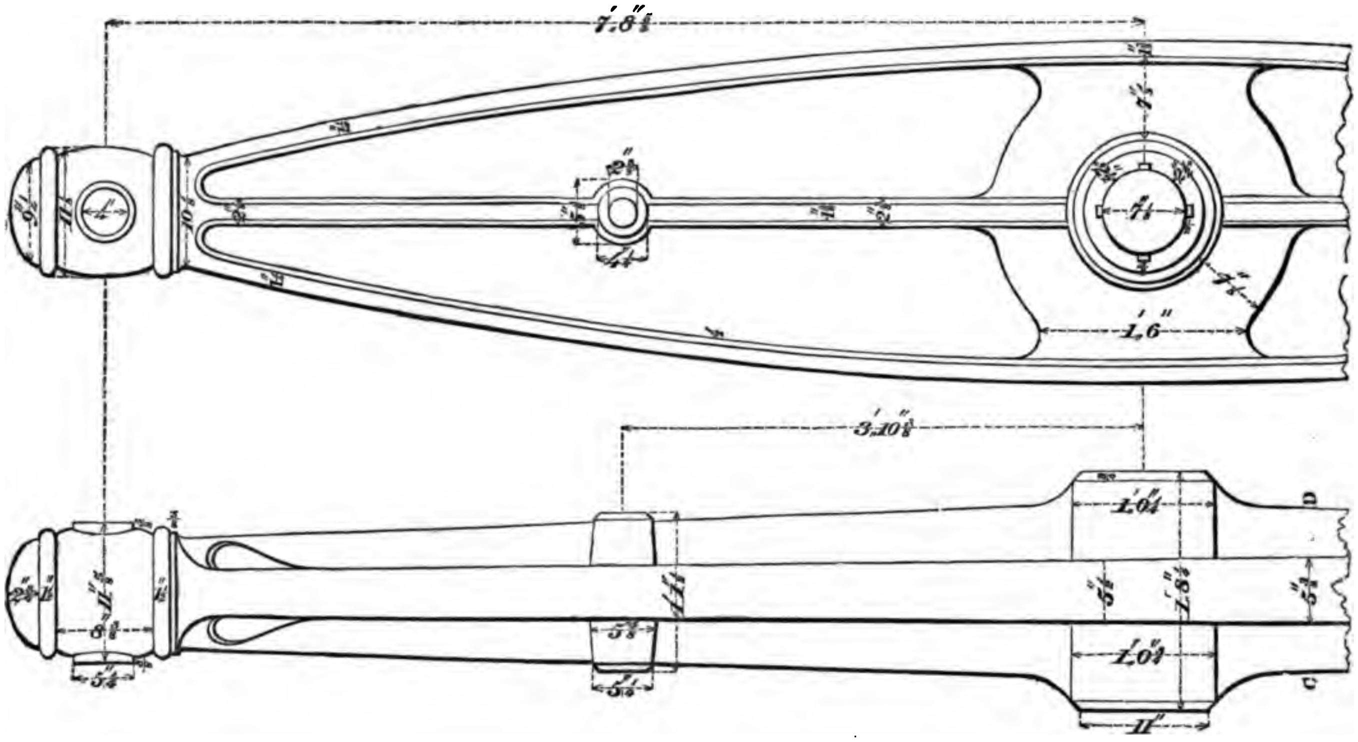
		CONSOLIDATED MINES.						UNITED MINES.			
		Taylor's engine.	Davy's engine.	Job's engine.	Woolf's engine.	Bawden's engine.	Pearce's engine.	Cardozo's engine.	Eldon's engine.	Loam's engine.	Hosking's engine.
Dimensions of engine.	Diameter of cylinder - - in inches.	85	80	65	90	90	65	90	30	85	85
	Stroke of piston - - in feet.	10	11⅓	9	10	10	9	9	9	10	10
	Diameter of steam-valve - in inches.	12	13	9	8	8	7	10	5	10	12
	„ equilibrium-valve „	16	18	12	16	16	12	13	7	16	16
	„ exhaustion-valve „	20	24	14	19	19	14	15	10	19	19
Dimensions of boilers.	Number of boilers - -	4	3	2	4	3	3	3	1	3	3
	Length of boilers - - in feet.	3·36 1·40	37	31 32	35	36	36	36	36	1·32 2·38	44
	Diameter of boilers - „	6½	7	6½	6¼	6¼	6¼	6¼	6½	6½	6½
	„ tubes - „	3·3¾ 1·4	4⅓	3¾	3¾	3¾	3	3¾	4	4	4
	Length of fire bars - „	4	4	4	4	4	4	4	4	4	4
	Total area of fire bars - „	63	52	30	60	45	45	48	16	48	48
	Heating surface exposed to flues „	3781	3151	1598	3481	2694	2694	2694	941	2952	3451
	Water space - - in cub. ft.	2467	2025	1033	2140	1650	1650	1650	579	1706	2085
	Steam space - - „	735	580	315	608	468	468	468	178	528	645
Temperatures observed.	Open air - - Frahrenheit.	57°	57°	-	57°	57°	51°	55°	56°	51°	55°
	Engine-house - - „	-	-	-	-	-	67°	-	55°	63°	66°
	Ashes over boiler - „	80°	80°	81°	98°	98°	97°	88°	99°	79°	82°
	Cylinder cover - - „	111°	90°	102°	126°	96°	109°	94°	98°	90°	84°
	Middle of cylinder clothing „	W 77°	W 76°	B 95°	B 102°	B 140°	-	B 79°	W 60°	W 67°	W 68°
	Clothing of steam-pipe - „	79°	-	-	130°	95°	-	140°	97°	80°	82°
	Condensing-water - „	64°	84°	58°	115°	110°	57°	60°	61°	63°	60°
	Hot well - - - „	98°	100°	91°	140°	140°	97°	104°	94°	102°	96°
	Height of condenser barometer in in.	27¼	27½	-	25½	-	-	-	-	-	27½
	Number of plunger-pumps -	9	12	2	7	8	9	8	1	5	5
	„ bucket-pumps -	2	2	-	1	2	2	2	-	4	3
	Water load per sq. in. of piston in lb.	11·46	13·12	8·78	11·56	8·3	16·8	11·5	17·96	11·95	13·58
	Proportion of stroke where steam cut off	⅓	⅓	-	⅓	⅓	¼	⅓	⅓	$\frac{2}{11}$	-
	Strokes per minute - -	8½	7½	-	9	9	10	8½	9	8	7
	Proportion of duration of in-door to out-door stroke - -	4 : 7	5 : 8	4 : 7	5 : 7	5 : 7	5 : 6	4 : 6½	4 : 7	1 : 2	4 : 7½
	Grease used per day - in lb.	12	12	10	12	12	10	12	6	12	12
	Oil used per day - - in pints.	1	1	1	1	1	1	1	½	1	1
	Men employed - - -	4	4	3	4	4	3	4	3	4	4
	Boys employed - - -	3	3	3	4	4	3	3	-	3	3

Fig. 243.



ROTATIVE HOUSE ENGINE OF TWENTY-FIVE HORSES' POWER, BY MESSRS. CAIRD AND CO.

Figs. 244, 245.



WORKING-BEAM.

¾ inch=1 foot.

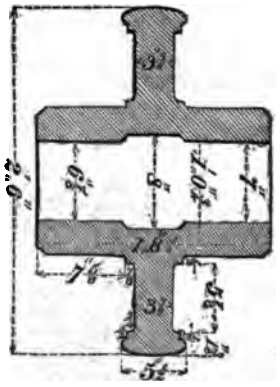
A bushel of coal was estimated by Mr. Watt to weigh 84 lb.: the Welsh coal, however, is denser than the other kinds, and a bushel of the coal now used in Cornwall weighs 94 lb.

ROTATIVE ENGINES.

We have already expressed our belief that rotative beam-engines must be superseded, even for land purposes, either by the oscillating or some other species of direct action engine; nevertheless, as all persons may not be of this opinion, and as this supercession has not yet taken place, we think it necessary to give the chief details of a rotative engine, and have selected an engine of Messrs. Caird's for this purpose, represented in *fig.* 243, which is a general elevation.

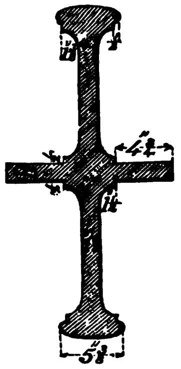
Figs. 244. and 245. are enlarged views of the working-beam, which is of cast-iron; and *figs*, 246. and 247. are sections of the same. The sizes of this beam agree, with tolerable nearness, with those given in our tables of dimensions. The depth of beam at the centre is usually about equal to the diameter of the cylinder, and the depth at the ends is generally made about one-third of the depth of the beam at the centre. The length of the beam is generally about three times the length of the stroke, and the thickness $\frac{1}{108}$th of the length. By the thickness is meant the mean thickness: the edge-bead is usually 1½ time the thickness of the web.

Fig. 246.



SECTION OF WORKING-BEAM AT CENTRE.

Fig. 247.



SECTION OF WORKING-BEAM THROUGH C D.

¾ inch=1 foot.

Fig. 248. is the cast-iron main centre of the working-beam; *fig.* 249. is the cast-iron stud for the main links; *fig.* 250. is the connecting-rod stud of cast-iron; *fig.* 251. is the wrought-iron stud for the air-pumps; *fig.* 252. is the wrought-iron stud for the hot and cold water pumps.

Fig. 248.

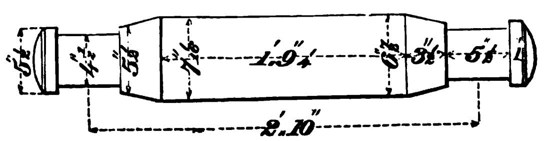


Fig. 249.

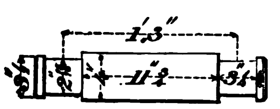


Fig. 250.

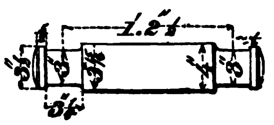


Fig. 251.

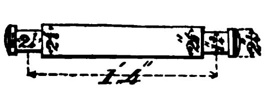
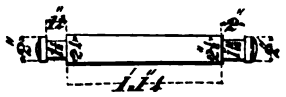


Fig. 252.



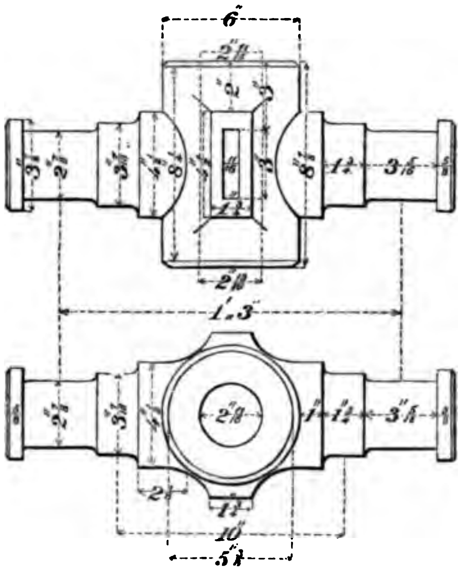
MAIN CENTRE AND STUDS OF WORKING-BEAM.

¾ inch=1 foot.

The diameter of the end studs of the beam is generally made about ⅛th of the diameter of the cylinder when the studs are of cast-iron, and $\frac{1}{10}$th of the diameter of the cylinder when they are of wrought-iron; but the larger proportion is preferable, as the wear of the brasses is then less rapid. It is a common fault to make bearings too small, from their proportionment being viewed with reference only to strength, whereas it should also be viewed with reference to wear.

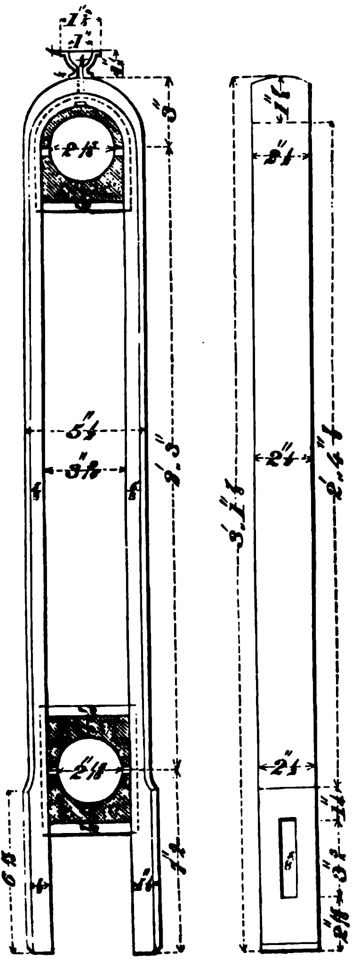
Figs. 253. and 254. are views of the piston-rod clutch or cross-head. The piston-rod passes into the round hole in the centre of the clutch, and the main links encircle the projecting bearings, and join the clutch with the main beam. *Fig.* 255. represents the cross-head gibs and cutter.

Figs. 253, 254.



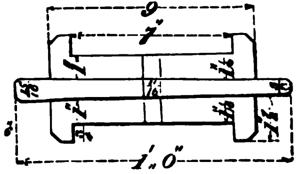
PISTON-ROD CROSS-HEAD.
1¼ inch=1 foot.

Figs. 256, 257.



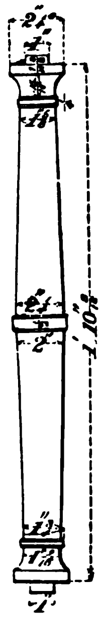
MAIN LINKS.
1¼ inch=1 foot.

Fig. 255.



GIBS AND CUTTER OF PISTON-ROD CROSS HEAD.
1¼ inch=1 foot.

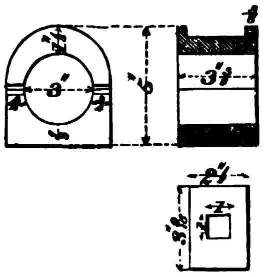
Fig. 258.



PILLAR OF MAIN LINKS.
1¼ inch=1 foot.

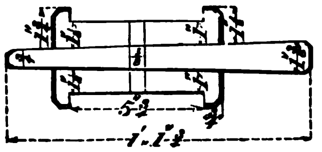
Figs. 256. and 257. represent the main links ; *fig.* 258. the pillar of the main link, which is interposed between the upper and under brasses; and *figs.* 259, 260, and 261. the upper brass and pillar plate of the link. *Fig.* 262. represents the gibs and cutter of the main links. The sectional area of the main links is usually made about $\frac{1}{113}$th of the area of the piston, that of the piston-rod being $\frac{1}{100}$th. To find the proper sectional area of the main links, a common rule is to divide the square of the diameter of the cylinder by 144. The length of the main links is usually about the same as the length of the crank, which is half the stroke. The main beam is always somewhat longer than the distance between the cylinder and crank centres, and at the cylinder end the perpendicular centre line divides the versed sine equally. The angular motion of the beam is about 38 degrees during the whole stroke. The length of stroke is the chord of the arc the centre of the end pin describes, and the versed sine represents the amount of deviation from the perpendicular, which is called the vibration of the beam. The beam being three times the length of the stroke, the distance from the main centre to the end stud is one and a half times the length of the stroke, and with these proportions the end stud will deviate from the perpendicular one inch for every foot of stroke. To find the amount of vibration of the end stud:—from the square of the radius in inches described by the stud subtract the square of the length of the crank in inches; extract the square root of the remainder, which deduct from the radius in inches. To find the proper distance between the main centre and the centre of the cylinder:—add the above-mentioned square root to the radius of the lever in inches; half their sum will be the horizontal distance in inches.

Figs. 259, 260, 261.



BRASSES OF MAIN LINKS.
1¼ inch=1 foot.

Fig. 262.



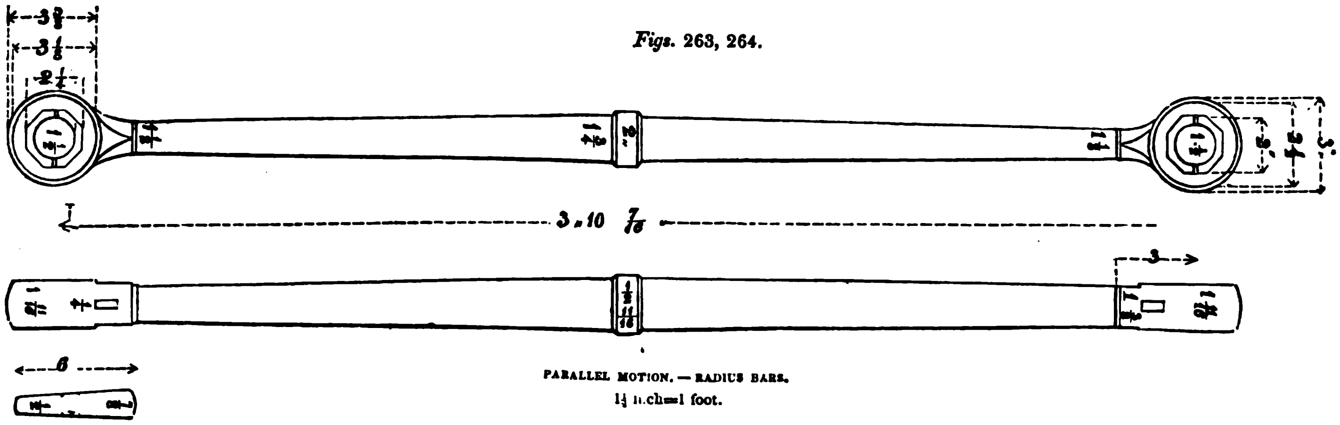
GIBS AND CUTTERS OF MAIN LINKS.
1¼ inch=1 foot.

The main centre of a land engine beam is usually fixed in with keys: the other centres are sometimes fixed with keys, and at other times they are ground in, which appears to be the preferable practice. The beam is set upon its edge, on two blocks of wood: a straight edge is applied to ascertain if it is nearly straight, and if bent or twisted it is brought straight by being hammered with the face of the hammer, though this practice weakens the beam if carried far. A cross piece of wood is put into each main-centre hole, upon which the central point is marked; the beam is plumbed, the end centres are put through, staked with wedges, and levelled by means of a short level with two legs passing down from the edge of the beam. The lengths from the main centre are next ascertained to be right, and the main centre is then put in, using the end centres as points to measure from. Finally, the keys are fitted. This is the mode of procedure when the holes for the centres are not bored out. It is expedient to put a centre line on the edge of the beam to fix the position of the studs laterally, and this is generally done. The force acting at each end of an engine-beam may be taken at 14 lbs. per circular inch of the piston, or, if the beam be supposed to be supported at both ends, it may be taken at 28lbs. per circular inch acting at the centre. The depth of the beam at the ends being one third of the depth at the middle, to find the dimensions at the middle, divide the weight in pounds acting at the centre by 250, and multiply the quotient by the distance in feet between the supports. To find the depth, the breadth being given; divide this product by the breadth in inches, and extract the square root of the quotient, which is the depth. It is expedient, however, to make main beams stronger than is indicated by any of these rules, as a higher pressure of steam is now used almost universally than was employed by Mr. Watt. In our table of the dimensions of beams at the centre, the figures given are understood to represent the web of the beam, or the dimensions within the beads, if the pressure of the steam be above that of the atmosphere.

We now come to the parallel motion. *Figs.* 263. and 264. represent the radius bars, and *figs.* 265. and 266. the parallel bars. The screws at the end of the parallel bars enter holes in the cross bar shown in *figs.* 267. and 268., and to the exterior bearings of the same cross-bar the radius-bars are attached, the other ends of those bars being attached to studs fixed to the spring beams in the line of the piston-rod.

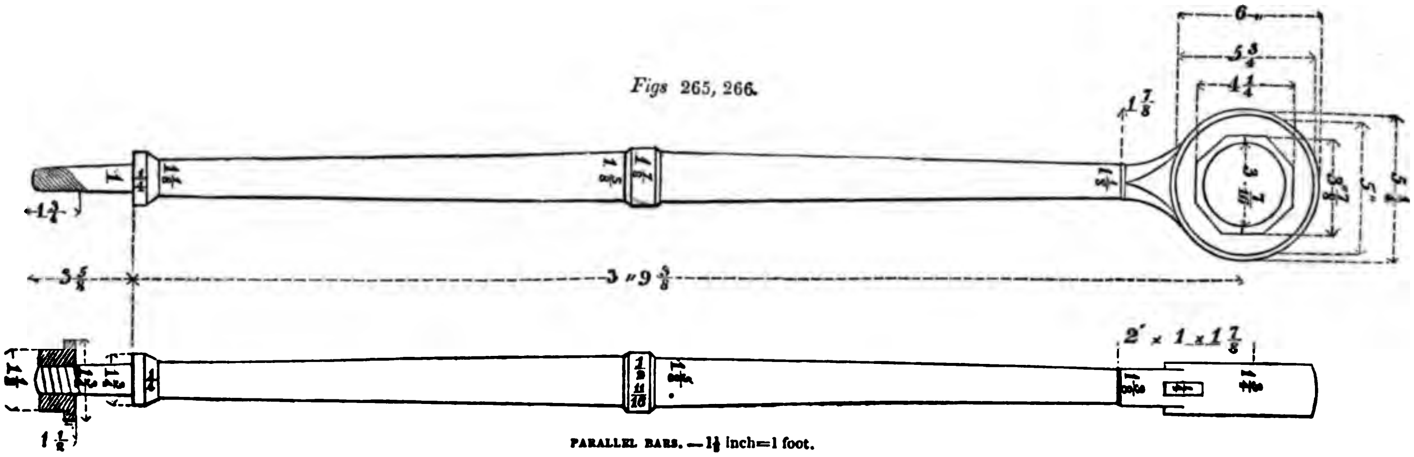
Figs. 269. and 270. represent the back links, the upper brass of which encircles the air-pump stud in the beam: the middle brass receives the cross-head on the top of the air-pump rod, and the lowest brass connects with the cross-bar of back links, *fig.* 268., through the oval hole in which

Figs. 263, 264.



PARALLEL MOTION.—RADIUS BARS.
1¼ inch=1 foot.

Figs 265, 266.



PARALLEL BARS.—1¼ inch=1 foot.

Fig. 269.

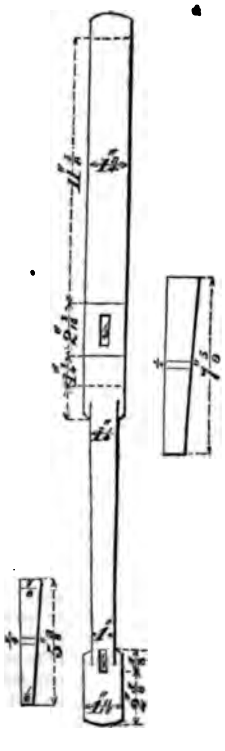
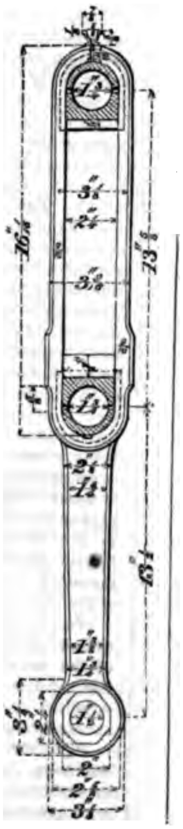
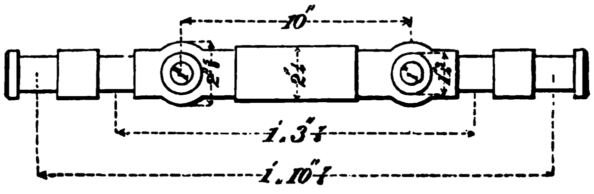


Fig. 270.



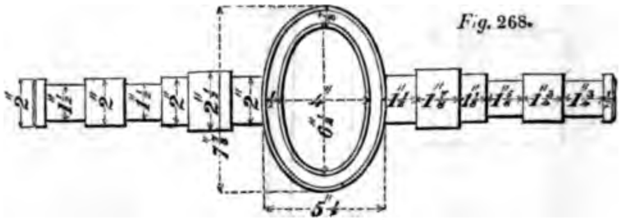
BACK LINKS — 1¼ inch=1 foot.

Fig. 267.



CROSS BAR OF BACK LINKS. SIDE VIEW.

Fig. 268.



CROSS BAR OF BACK LINKS. BIRD'S-EYE VIEW.
1¼ inch=1 foot.

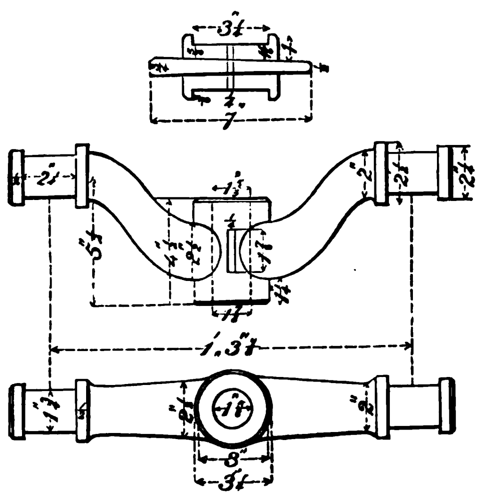
the air-pump rod passes. The sectional area of the back links is made the same as that of the air-pump rod, which is one tenth of the diameter of the air-pump, or one twentieth of the diameter of the cylinder. The sectional area therefore of the two back links taken together is equal to the area of a circle one twentieth of the diameter of the cylinder; but in practice they are generally made of somewhat stronger proportions.

We have already given at page 18. an explanation of the manner in which the parallel motion acts, and at page 100. we have given rules for computing the lengths of the principal rods and levers, while at pages 136. and 154. we have given the strengths of the parts in engines of different powers. The best proportionment of the parallel motions of land engines, and that now followed universally, consists in making the radius and parallel rods of exactly the same length, and this length equal to half the radius of the great beam. The stud from which the back links are hung is in this case situated midway between the main centre and the end stud of the beam, and the studs in the spring beams round which the radius bars move, are in the same vertical line as the centre of the cylinder. To find, therefore, the right position for those studs, measure down perpendicularly from the centre of the end stud, when the beam is level, to a distance equal to the length of the main or back links, and at this distance draw a horizontal line on the inner sides of the spring beams. Then set off from the main centre on this line the distance between the main centre and centre of the cylinder: the point of intersection is the right position of the studs in the spring beams to which the radius or bridle rods are attached. In Mr. Watt's early engines the radius rods were made longer than the parallel rods, and were attached to a shaft which passed across between the spring beams clear of the end of the working beam; but the universal practice now is to introduce studs into the spring beams, whereby the parallel and radius bars may be made of the same length, and this is in every way a preferable arrangement.

The back links and the main links are always of the same length, and their length was, according to Mr. Watt's practice, three-sevenths of the stroke, but they are now generally made half the length of the stroke, or the length of the crank, as we have already stated. The air-pump cross head is inserted in the back links at the middle of their length. This point in the back links moves, it is obvious, in the vertical line, for as the top of the links follows the motion of the main beam, and the bottom that of the radius bars, which have the same radius and the same length of motion as the stud in the beam from which the links are suspended, the central point of the links will have motion in a curve equally removed from that of each end, which will be a straight line very nearly. The line traced by the parallel motion is not precisely a straight line, but a species of S curve; it approaches to a straight line, however, with sufficient nearness for every practical purpose. Notwithstanding the elegance of the parallel motion, as an expedient for maintaining the perpendicular position of the piston-rod, it is questionable whether guides are not to be preferred. In America they are very generally used, even with very long strokes and very short beams; and in some of the steam vessels in this country they have been substituted with advantage. The adjustment of parallel motions is a difficult task in the hands of ignorant persons; and unless the parallel motion be very true it will be difficult to keep good packing in the stuffing-box, and the cylinder will speedily be worn oval. If guides be used, it appears to us expedient that they should consist of strong round rods, and that the eyes at the ends of the cylinder cross-head should be formed into stuffing-boxes, which may be tightened up when the holes wear. The ends of the rods must rest in sockets cast on the cylinder, and the cylinder cover should not be made tight with gasket, which may be compressed more in one part than in another, but should be formed with a metallic joint. If a parallel motion, however, be preferred to the guides, we should suggest its being made in fewer pieces. We see no use whatever in making the main or back links to consist of pillars and straps. Engineers have become wedded to this species of architecture, and the combination is satisfactory to their associations, but unbiassed judges, we humbly conceive, would prefer suitable pieces of solid iron, with holes and brasses in the right places. If guide-rods be used, however, such as we have suggested, it will be necessary to make the lower portions of the main links with straps and cutters, as in the connecting-rod of a marine engine; as the stuffing-boxes at the ends of the cross-head, for the reception of the guide-rods, could not be passed through holes in the links.

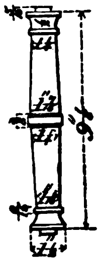
Figs. 271. and 272. represent the air-pump cross-head, which fits into the central brasses of the back links. *Fig.* 273. is the pillar which fits between the brasses; and *figs.* 274, 275, and 276., are different views of the brasses, &c. of the air-pump cross-head. The proportions of various parts of parallel motions we have already given in page 136: the parts appertaining to the air-pump are made of the size that would be requisite for a cylinder of the same diameter.

Figs. 271, 272.



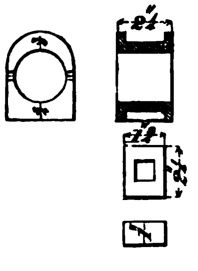
AIR-PUMP ROD CROSS-HEAD.
1½ inch=1 foot.

Fig. 273.



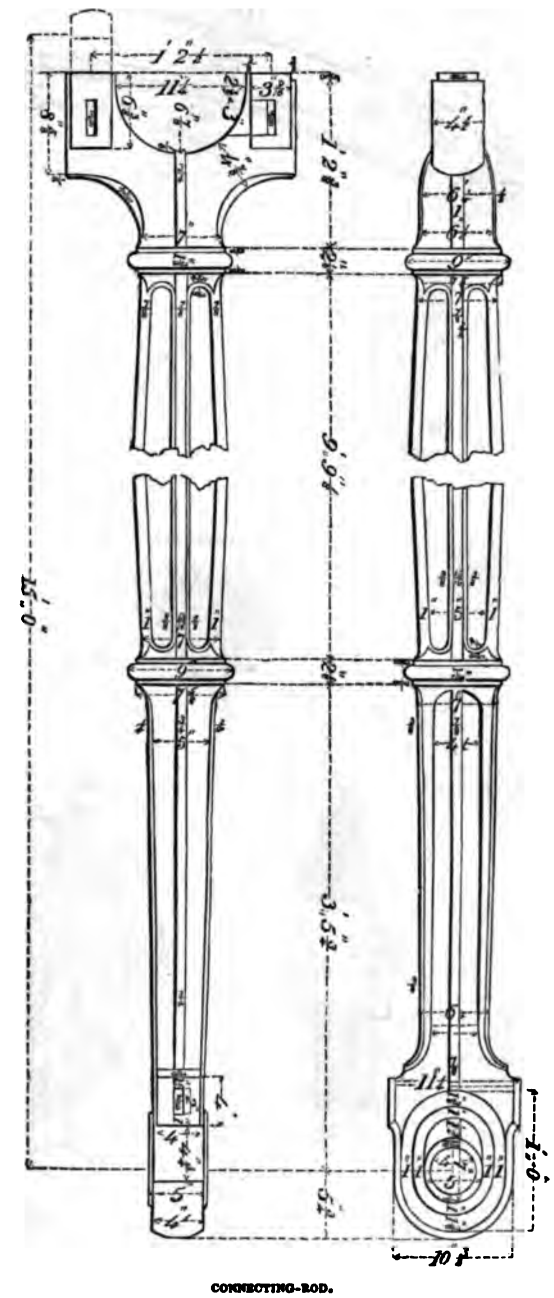
PILLAR OF BACK LINKS.
1½ inch=1 foot.

Figs. 274, 275, 276.



BUSH OF AIR-PUMP CROSS HEAD.
1½ inch=1 foot.

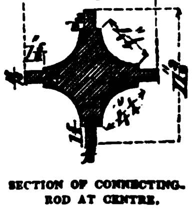
Figs. 277, 278.



CONNECTING-ROD.
¾ inch=1 foot.

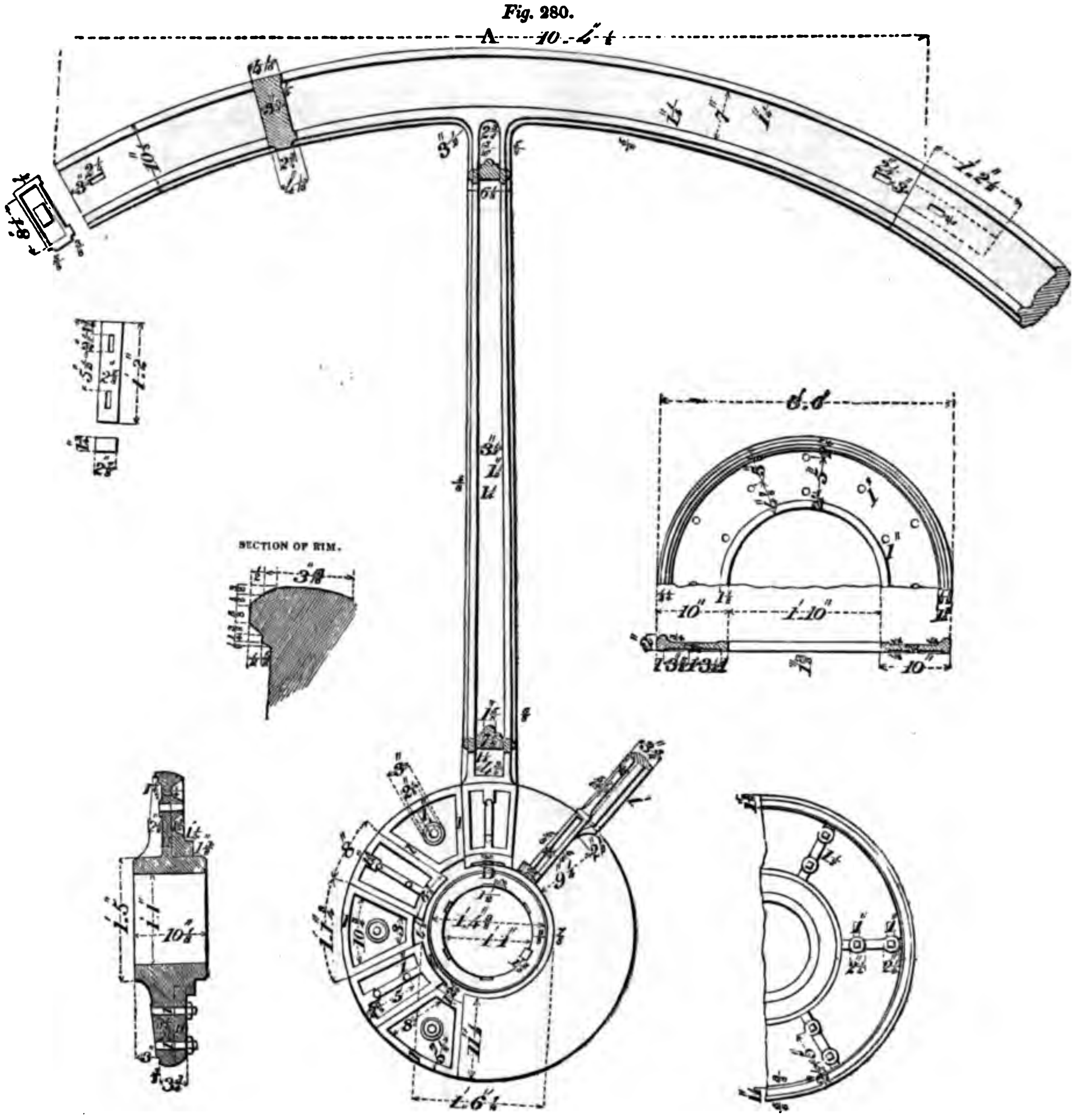
Figs. 277. and 278. are views of the connecting-rod, which is of cast-iron. Malleable iron connecting rods are now coming into use for land engines, and they are in every way preferable. When the connecting-rod is of cast-iron, of the form represented in the figure, the breadth across the arms of the cross is made about $\frac{1}{20}$th of the length of the rod; the sectional area at centre of rod $\frac{1}{25}$th of the area of the cylinder, and the sectional area at ends of rod $\frac{1}{35}$th of the area of the cylinder. *Fig.* 279. shows the form of sectional area at centre. The length of the connecting-rod is generally made about three times the length of the stroke. The diameter of the crank pin is about one sixth of the diameter of the cylinder, and is generally made of cast-iron in land engines. The gudgeons of water wheels are generally loaded with about 500 lbs. for every circular inch of their transverse section, which is nearly the proportion which obtains in the end studs of engine-beams, but the main centre is usually loaded beyond this proportion. To find the proper size of a cast-iron gudgeon adapted to sustain a

Fig. 279.



SECTION OF CONNECTING-ROD AT CENTRE.
¾ inch=1 foot.

Fig. 280.



FLY-WHEEL.— Scale ½ inch=1 foot.

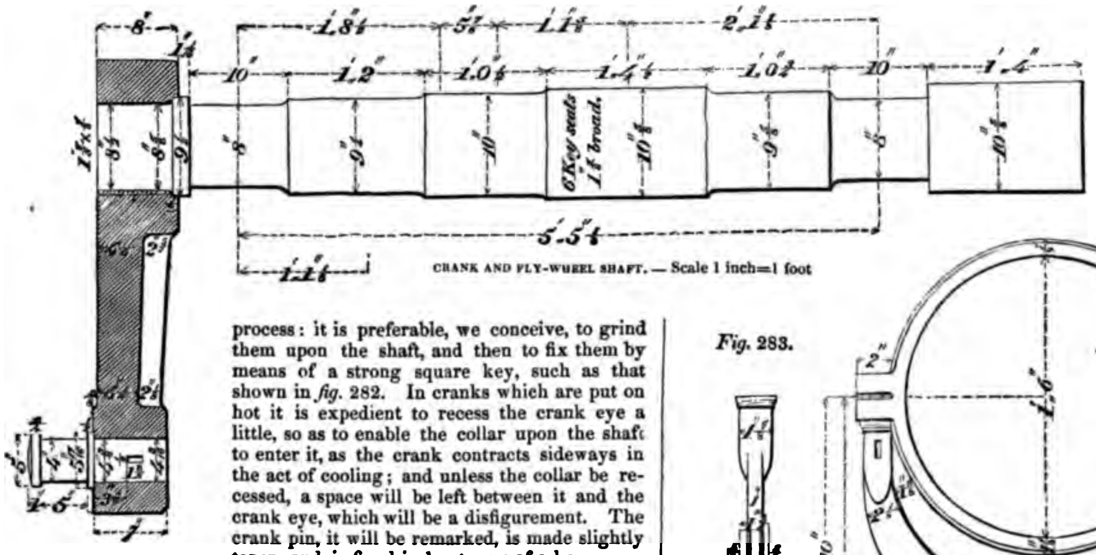
given weight, multiply the weight in pounds by the intended length of bearing expressed in terms of the diameter, divide the product by 500, and extract the square root of the quotient, which is the diameter in inches. For malleable iron the operation is the same, but the divisor may be made 1000 instead of 500. These strengths are not intended to resist torsion, but are those proper for gudgeons. Experiments upon the force requisite to twist off cast-iron necks show, that if the cube of the diameter of the neck in inches be multiplied by 880, the product will be the force of torsion in pounds which will twist them off when acting at 6 inches radius. The strength for cast-iron crank shafts may be determined by multiplying the square of the diameter of the cylinder in inches by the length of the stroke in feet, multiplying by the decimal ·15, and extracting the cube root of the product, which is the proper diameter of the shaft-neck in inches. This rule has reference not merely to torsion, but also to the strength as a gudgeon necessary to sustain the fly-wheel.

We have already, in pages 157. and 165., given rules for determining the proportions of fly-wheels. Messrs. Fenton and Murray use the following rule for determining the weight of the fly-wheel, which is simpler perhaps than those we have given: — Multiply the number of horses power of the engine by 2000, and divide the product by the square of the velocity of the circumference of the fly-wheel in feet per second: the quotient is the proper weight of the fly-wheel in hundred weights. To find the weight of the rim of a fly-wheel in pounds, multiply the mean diameter of the rim in feet by the area of its transverse section in square inches, and multiply the product by 9·817 lbs. This gives the weight of the rim in pounds when the sectional area is determined, as may be done by the rule given at page 157. Mr. Farey gives the following rule for determining the proper quantity of cast-iron in a fly-wheel in cubic feet: —Multiply the mean diameter of the rim by the number of its revolutions per minute, and square the product for a divisor; divide the number of horse power exerted by the engine by the number of strokes the piston makes per minute; multiply the quotient by the constant number 2,760,000, and divide the product by the divisor found as above. The quotient is the requisite quantity of cast-iron in cubic feet to form the fly-wheel rim.

In large engines each arm is cast separate, and after having been fitted to the central boss, the rim of the wheel is fitted to the arms in segments. In small engines, such as that of which the fly-wheel is shown in *fig.* 280., an arm and a segment are generally cast together. In mill engines it appears expedient to work with a short stroke and rapid piston, whereby the fly-wheel is made more effectual, or a smaller one will suffice. Combined oscillating engines, working with a high speed, will probably come into extensive use for turning mills; and if the arrangements be judiciously made, the fly wheel may in time be dispensed with altogether.

We have given rules for proportioning cast-iron cranks in page 156., and have little now to add upon the subject. We do not approve of the plan of putting cast-iron cranks on hot, as the eye is liable to be cracked in the

Fig. 281.



CRANK AND FLY-WHEEL SHAFT. — Scale 1 inch=1 foot

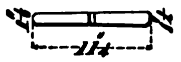
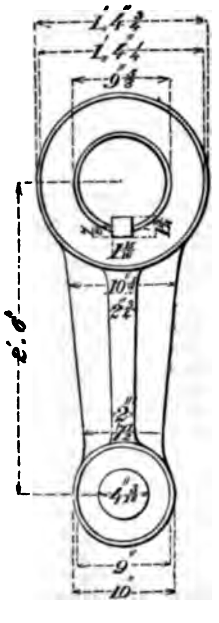


Fig. 282.



process: it is preferable, we conceive, to grind them upon the shaft, and then to fix them by means of a strong square key, such as that shown in *fig.* 282. In cranks which are put on hot it is expedient to recess the crank eye a little, so as to enable the collar upon the shaft to enter it, as the crank contracts sideways in the act of cooling; and unless the collar be recessed, a space will be left between it and the crank eye, which will be a disfigurement. The crank pin, it will be remarked, is made slightly taper, and is fixed in by means of a key.

As nearly all rotative land engines give motion to mill-work, we shall here give some rules for proportioning the teeth of wheels. The diameters of toothed wheels should always be such as to enable a number of teeth to be in action at the same time; and pinions should not have less than thirty or forty teeth to enable them to work satisfactorily. Bevelled wheels act better than spur wheels, and wheels with internal teeth better than either; for the more nearly the lines of motion approximate, with the less velocity and shock will the teeth come together. Wheels are usually made with one tooth more or less than a number that will divide the teeth of each equally: this tooth is called a "hunting cog," and its effect is to bring every tooth of the one wheel successively in contact with every tooth of the other. In speeds above 220 feet in the minute, wooden teeth should be introduced in the larger wheel, and these teeth should be a little thicker than the iron teeth, to make them of equal strength. To find the proper dimensions of the teeth of a cast-iron wheel which is required to transmit a given power, Mr. Farey proposes to multiply the diameter of the pitch circle in feet by the number of revolutions to be made per minute, and reserve the product for a divisor. Multiply the number of horse power to be transmitted by 240, and divide the product by the above divisor: the quotient is the strength. If the pitch be given, to find the breadth divide the above strength by the square of the pitch in inches; or if the breadth be given, then to find the pitch divide the strength by the breadth in inches, and extract the square root of the quotient, which is the proper pitch for the teeth in inches. Mr. Hick gives the following rule for computing the power that the teeth of wheels are capable of transmitting: — Multiply one fourth of the square of the pitch in inches by the breadth of the teeth in inches: the product is the number of horse power that the teeth will transmit when the pitch line passes through 4 feet per second. The length of the teeth, or their projection from the rim of the wheel, is usually about five eighths of the pitch. The breadth of teeth varies from 1½ to 4 times the pitch, the greatest breadth being made where there is the greatest liability to wear. If only one pair of teeth be supposed to be in contact, the force transmitted by teeth in average cases may be taken at 550 lbs. for each square inch of surface in contact. In several recent instances wheels have been made in steps, or a wide wheel has been compounded of several narrow wheels set in contact on the same shaft, but the teeth of each slightly in advance of the teeth of the next succeeding, so that the pitch is divided, and the necessary strength is reconciled with what is virtually a fine pitch.

Figs. 283. and 284. are representations of the eccentric rod, and *figs.* 285. to 289. are views of the several parts of the governor. We have given in page 168. rules for determining the proportions of governors, and the arrangement of the parts here figured will be apprehended by a reference to *fig.* 243. *Fig.* 285. is the upright revolving spindle on which the collar,

Fig. 283.

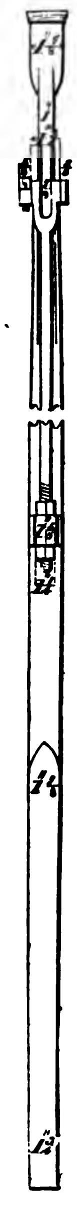
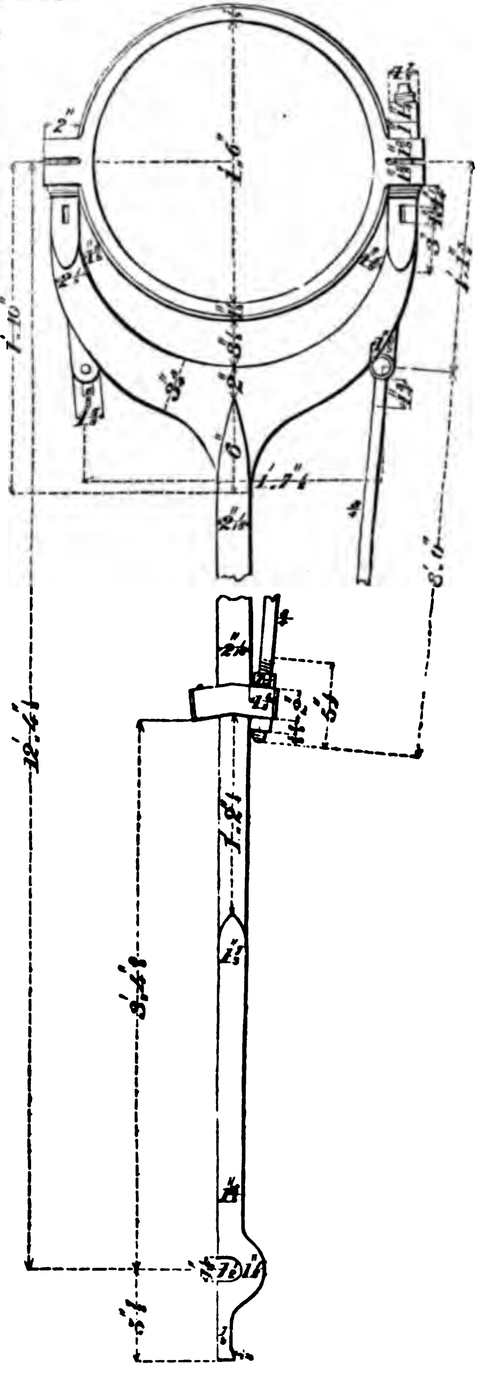


Fig. 284.



ECCENTRIC HOOP AND ROD.
Scale 1 inch=1 foot.

Fig. 285.

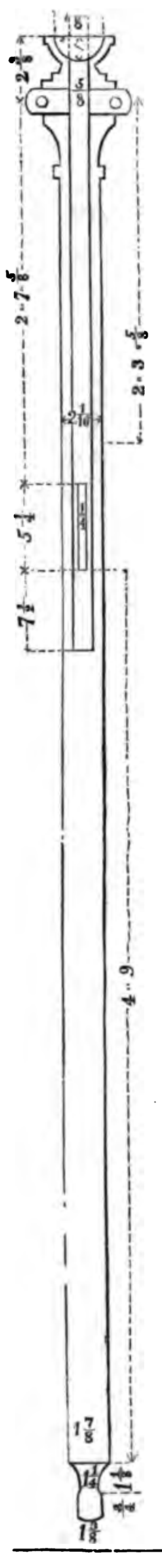


Fig. 286.

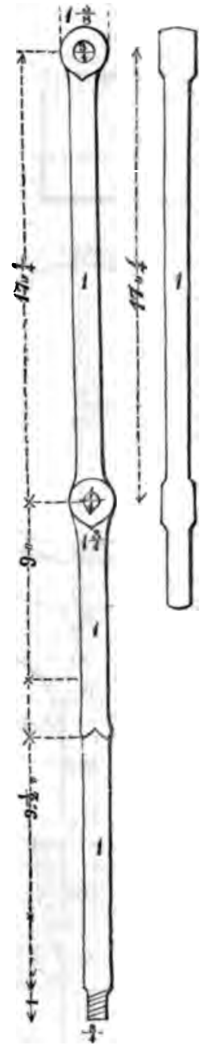
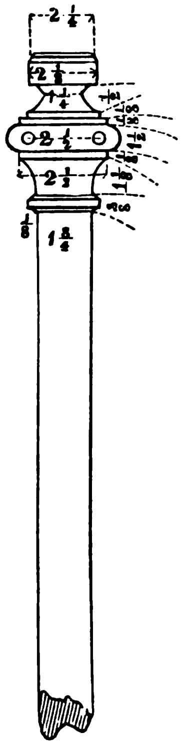
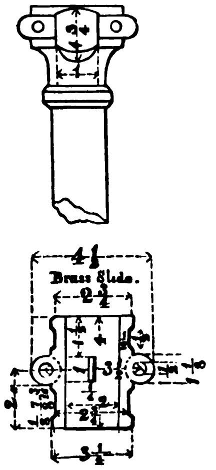


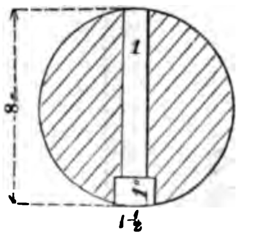
Fig. 287.



GOVERNOR SPINDLE.

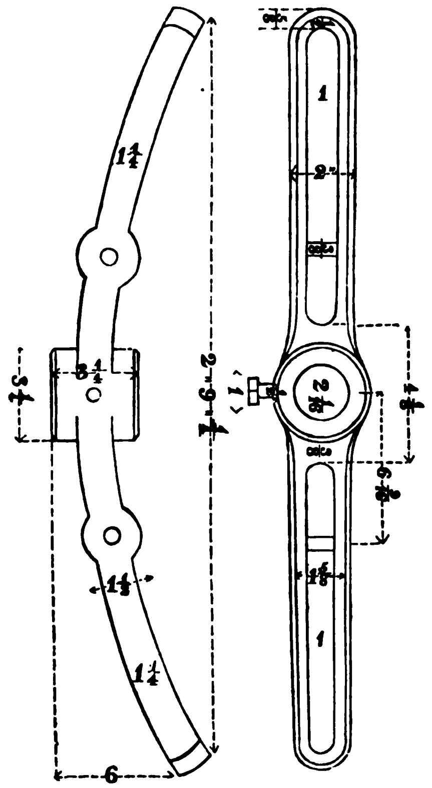
Fig. 288.





PARTS OF THE GOVERNOR.

Fig. 289.



GUIDES OF GOVERNOR ARMS.

shown in section with sizes in *fig.* 288., slides, and the curved guide, *fig.* 289., is fixed. From the top of the spindle, *fig.* 285., the arms, *fig.* 286., are suspended, with the balls at the end, the arms moving in the slit in the curved guides, *fig.* 289. The divergence or collapse of the balls causes the collar to slide up or down on the spindle; and through a slit shown in the spindle (which is hollow), this movement is communicated to a rod sliding within it, which, by a suitable attachment, moves the throttle-valve. This arrangement of governor is very neat and convenient, and commends itself to general adoption.

Messrs. Boulton and Watt have supplied us with a statement of the speed of the piston in their engines of different powers, and it is as follows: —

	Feet.	Ft. in.	Feet.	Ft. in.	Feet.	Feet.	Feet.	Feet.	Feet.
Length of stroke - -	2	2 6	3	3 6	4	5	6	7	8
No. of strokes per minute	40	34 0	30	27 0	25	21½	19	17½	16
Feet travelled per minute	160	170 0	180	189 0	200	215	228	245	256

These speeds agree with those given by Mr. Farey, in a table, from which the following is an extract: —

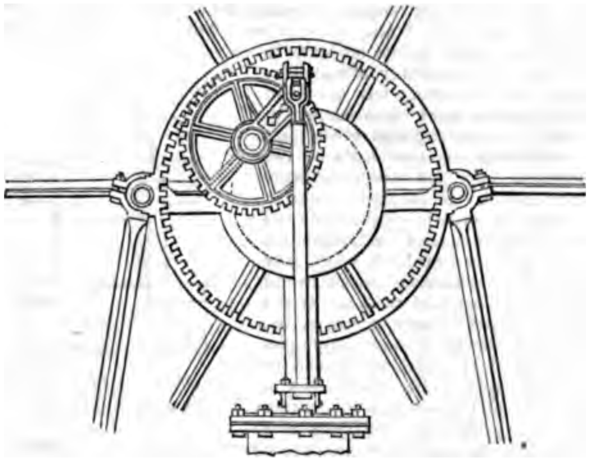
Horse Power.	Diameter of Cylinder.	Length of Stroke in Feet.	Number of Strokes per Minute.	Speed in Feet per Minute.	Effective Pressure per Square Inch in Lbs.
4	12	3	29	174	6·8
6	14	3½	27	189	6·82
8	16	4	24	192	6·84
10	17½	4	25	200	6·86
12	19	4	25	200	6·88
14	20⅝	4	25	200	6·91
16	21¾	4½	23	207	6·91
18	23	4½	23	207	6·91
20	23¾	5	21½	215	6·92
22	25	5	21½	215	6·92
24	26	5	21½	215	6·92
26	26¾	5½	20	220	6·92
28	27⅞	5½	20	220	6·92
30	28¼	6	19	228	6·92
36	30⅞	6	19	228	6·92
40	31½	7	17½	245	6·92
45	33¼	7	17½	245	6·92
50	35⅛	7	17½	245	6·94
60	38½	7	17½	245	6·94
70	40¾	8	16	256	6·94
80	43½	8	16	256	6·94
90	46½	8	16	256	6·94
100	48⅝	8	16	256	6·94

In this table the pressure is taken to vary slightly with the size of the engine; but Messrs. Boulton and Watt notify to us that, though such was the manner in which they formerly treated the subject, they now adopt a uniform pressure of 7 lbs. on the square inch, as a preferable element of computation. The effect of this substitution is to make small engines of a somewhat greater nominal power than they formerly were reckoned at, which, since the nominal power is now a commercial unit, as well as a scientific one, is convenient in approximating the price per horse-power of the different sizes. The speed of the piston in feet per minute is about 128 times the cube-root of the stroke; and, as has already been mentioned, the nominal horse-power of an engine may be found by multiplying the square of the diameter of the cylinder in inches by the cube-root of the stroke in feet, and dividing by 47. To find how many millions of pounds are raised 1 foot high by the consumption of a bushel or 84 lb. of coal:— Divide 166·32 by the number of pounds of coal consumed per hour by each horse power: the quotient is the number of millions of pounds raised 1 foot high by the consumption of 84 lbs. of coal. A bushel of Newcastle coal will weigh about 84 lbs., but the Welsh coal is heavier.

If a cubic inch of water be supposed to produce a cubic foot of steam, and the latent heat of steam at 212° be taken, with Mr. Watt, at 960°, or, in other words, the cubic foot of steam be supposed to contain as much heat in the latent form as would raise the temperature of the cubic inch of water, if it could be prevented from expanding, 960°, then the sum of the latent and sensible heats will be represented by 1172°. The temperature of the water discharged by the air-pump is about 100°, which, taken from 1172°, leaves 1072°, which must be taken up by such a quantity of cold water that its temperature will not rise above 100°. If the temperature of the injection water be 50°, then the difference between that and 100°, viz. 50°, is available for the absorption of the heat; and 1072 divided by 50 = 21·44, which is the number of times the quantity of injection water must exceed the quantity of water in the steam. To condense a cubic inch of water therefore in the shape of steam, 21·44 cubic inches of injection water are necessary; but inasmuch as the water may not always be as cold as 50°, Mr. Watt's practice was to allow a wine pint, or 28·9 cubic inches of injection water for every cubic inch of water converted into steam. The capacity of the cold-water pump is usually made from one thirty-sixth to one forty-eighth of the capacity of the cylinder. The injection orifice should have an area of about one fifteenth of a square inch per horse power. The capacity of the hot-water pump should be about one 240th of that of the cylinder, supposing that the engine is double-acting, and the pump single-acting. The air-pump is usually made half the diameter of the cylinder, and half the stroke, or one eighth of the capacity. The power requisite to work the air-pump is from one thirtieth to one fortieth of the power of the engine. The openings through the foot and delivery valves are made of about one fourth of the area of the pump. The internal diameter of the steam-pipe may be found by dividing the horse power by ·8, and extracting the square root of the quotient. We shall reserve what we have to say on the subject of bolts until we come to speak of the holding-down bolts of marine engines.

There are many other kinds of parallel motion besides those which we have mentioned, but there are none of them of sufficient importance to justify a lengthened description. *Fig.* 290. represents a species of parallel motion invented by Mr. James White, and published in his "New Century of Inventions," in 1801. It depends on the principle that an encycloidal curve, formed by one circle rolling within another, becomes a straight line when the diameter of the outer circle is just twice that of the inner one. A large wheel, with teeth on its inner circumference, is fixed on a frame concentric with the axis and circle of the crank. A wheel with external teeth is fixed freely on the crank-pin and the point of attachment of the piston-rod. By this arrangement the small wheel is compelled, by the pressure of the piston-rod upwards, to roll round the great circle, ascending on the one side, and descending on the other, so that the distance of the end of the piston-rod from the point of contact of the circles is always equal to the distance of the circle from the diameter. The fault of this species of parallel motion is, that the socket in the centre of the revolving wheel is exposed to a strain equal to twice that on the piston, and which it cannot conveniently be made long enough to resist, so that it is liable to break or speedily shake loose. In the plate of direct-action engines, various modifications of the parallel motion will be observed. In the Gorgon engine, by Messrs. Seaward, the parallel motion is formed by the application of a radius-bar to the air-pump lever, whereby one radius is made to counteract the other — the centre of the lever resting upon a jointed pillar, in order to enable the cylinder end of the lever to move up and down in a vertical line. This species of parallel motion is sometimes made with a horizontal slide for the centre to move in, instead of a vibrating pillar or link; but a slide works slack sideways, and is not satisfactory in practice. The combination might be improved by causing the sliding ends of the rods, which in some cases are used instead of a lever, to work into stuffing-box tubes hung on a centre, so as to enable them to swivel. The rods, so soon as any wear took place, could be tightened afresh by screwing up the packing.

Fig. 290.



MARINE ENGINES.

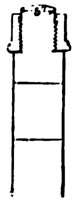
Cylinder. — In the marine engine the cylinder-bottom is more frequently cast in, than in land engines, and a plug of metal is fitted into a hole in the centre of the bottom, which is left to allow the boring-bar to pass through. It is necessary that the cylinder should be bolted very firmly to the sole plate, as in engines which exhaust at the under side of the valve-casing, an air-tight joint has to be made between the sole plate and the part of the cylinder-bottom next to the valve. A cylinder of about 6 feet diameter is usually made about 1½ inch thick, and the metal should be hard as well as solid. Messrs. Maudslay's practice in side-lever engines is to cast the cylinder-bottom in, up to 60 inches diameter, and above that size they prefer casting the cylinder open at the bottom, and making the bottom out of the sole-plate. A projection is cast on the sole-plate, to go a certain distance into the cylinder, with a space hollowed out for the cylinder-port. The bottom joint should not be of rust, but metal to metal — the bottom flange of the cylinder and the place on which it stands on the sole-plate being both faced in the boring-mill. The cylinder-cover should fit so nicely as to be tight, by interposing a piece of lead or a ring of wire gauze, smeared with white or red lead. In oscillating engines the cylinder-bottom is generally cast in, whatever be the size of the cylinder.

The valve-casing should be attached to the cylinder by means of a metallic joint, or, in other words, by fitting the surfaces so accurately that a little red lead interposed will make them tight. The valve-casing can thus be easily removed at any time to repair the valve faces; whereas, if the joint of the casing be of rust, the removal of the casing is an operation of much difficulty. The attachments of the cylinder to the diagonal stay are very generally made too small; that is, the surface is too small, and the flange too thick. A very thick flange cast on any particular part of a cylinder endangers the soundness of the cylinder by inducing an unequal contraction. It is much the best way to make the flange for the framing thin, and the surface large. The bolts, too, should be turned bolts, and nicely fitted. Some persons make them with a nut at both ends, the body of the bolt being made with a little taper; and the nut which answers to the head is screwed up after the conical part of the bolt has been drawn into the hole by the nut at the point. The object of this plan is to facilitate the fitting; but if the fitting be well done, it is unimportant whether it is done in this way or any other.

Cylinders are not now usually made with steam-casings, yet experiment has satisfactorily proved that there is a loss of power consequent on their relinquishment. It is not very easy to discern the cause of this loss, as there is more radiating surface in the casing than in the cylinder; yet the existence of the loss is very certain. Mr. Watt, in some of his early trials, discontinued the steam-jacket; and he found the consumption of fuel to be materially increased. He therefore again resumed it, but it has been again discarded in most of the modern engines, except those of the Cornish construction. Escape-valves, for letting out any water that may enter with the steam, are now usually employed in marine engines: they may in most cases be applied conveniently to the ports of the cylinder, as shown in the details of engines of the West India packets, and may be kept shut by a spring, in the same manner as the safety-valve of a locomotive. Escape-valves should be placed on that side of the cylinder which is nearest the side of the ship; so that the attendants may not be scalded by the issuing water if the engine primes. The escape-valve is shown beneath the "Plan of Cylinder" in the West India mail engine details; and to those details the remarks which follow are to be understood to refer, except where specified to the contrary. In boring cylinders of 74 inches diameter, the boring-bar must make one revolution in about 4½ minutes, so that the cutters will move at the rate of about 5 feet per minute. In boring brass the speed must be slower: the common rate at which the tool moves in boring brass air-pumps is about 3 feet per minute. If this speed be exceeded the tool will be spoiled, and the pump made taper. The speed proper for boring a cylinder will answer for boring the brass air-pump of the same engine. A brass air-pump of 36½ inches diameter requires the bar to make one turn in about 3 minutes, which is also the speed proper for a cylinder 60 inches in diameter. To bore a brass air-pump 36½ inches in diameter requires a week, an iron one requires 48 hours, and a copper one 24 hours. In turning a malleable iron shaft, 12¾ inches in diameter, the shaft should make about five turns per minute, which is equivalent to a speed in the tool of about 16 feet per minute. A boring-mill, of which the speed may be varied from one turn in six minutes to twenty-five turns in one minute, will be suitable for all ordinary wants that can occur in practice.

Piston. — We have nothing further to say on the subject of pistons, after the various specimens we have already given. The proportion of taper given to the piston-rod where it fits into the piston, in the West India mail engines is a good one; if the taper be too small, the rod is drawn through the hole, and the piston is split. Small grooves are turned out of this piston-rod above and below the cutter-hole, and hemp is introduced, in order to make the piston-eye tight. Most piston-rods are fixed to the piston by means of a gib and cutter, as shown in the plates of details, but in some cases the upper portion of the rod within the eye is screwed, and it is fixed into the piston by means of an indented nut. This nut is in some cases hexagonal, and in other cases the exterior forms a portion of a cone, which completely fills a corresponding recess in the piston. But nuts made in this way become rusted into their seat after some time, and cannot be started without much difficulty. Messrs. Miller, Ravenhill, and Co. fix in their piston-rods by means of an indented hexagonal nut, which may be started by means of an open box key. The thread of the screw is made flat upon the one side, and much slanted on the other, whereby a greater strength is secured, without any disposition to split the nut. When pistons are made of a single ring, or of a succession of single rings, the strength of each ring is tested previously to its introduction into the piston, by means of a lever loaded by a heavy weight. The old practice was to depend chiefly upon grinding, as the means of making the rings tight upon the piston or upon one another; but scraping is now chiefly relied on. A slight grinding, however, with powdered Turkey stone appears to be expedient, which may be most conveniently accomplished by setting the piston on a revolving table, and holding the ring stationary by a cross piece of wood while the table turns round. Pieces of wood may be interposed between the ring and the body of the piston, to keep the ring nearly in its right position; but these pieces of wood should be fitted so loosely as to give some side-play, else the ring will wear itself into a groove on the piston. Messrs. Penn grind their cylinders after they are bored, by laying them on their side, and rubbing a heavy piece of lead, made to the curve of the cylinder, and smeared with emery and oil, backwards and forwards by hand, the cylinder being gradually turned round, so as to subject every part successively to the operation. The pistons are also ground into the cylinders with great care, so that they are perfectly tight from the commencement. Messrs. Penn's piston for oscillating engines has a single packing ring, with a tongue-piece, as in Messrs. Maudslay's and Messrs. Miller's arrangements, figured in pages 197 and 193. The ring is packed behind with hemp-packing, and the piece which covers the joint is made of sheet copper, and is indented into the iron of the ring, so as to offer no obstruction to the application of the hemp. The ring is ground to the piston only on the under edge: the top edge is rounded from the inside to a point, and the junk-ring does not bear upon it, but the junk-ring squeezes down the hemp-packing between the packing-ring and the body of the piston. The metallic packing of the piston consists of a double tier of rings, cut into numerous segments. We approve of the plan of adding a nut to the top of the piston-rod, in addition to the cutter, for securing the piston-rod to the cross-head, as shown in *fig.* 291., where the piston-rod is 7 inches in diameter, and the screw 5 inches: the part of the rod which fits into the cross-head eye is 1 ft. 5½ inches long, and tapers from 6½ to 6$\frac{13}{16}$ inches diameter. The proportion of taper is a good one: if the taper be less, or if a portion of the piston-rod within the cross-head eye be left untapered, as is sometimes the case, it is very difficult to detach the parts from one another, and we have known great inconvenience to be thus occasioned.

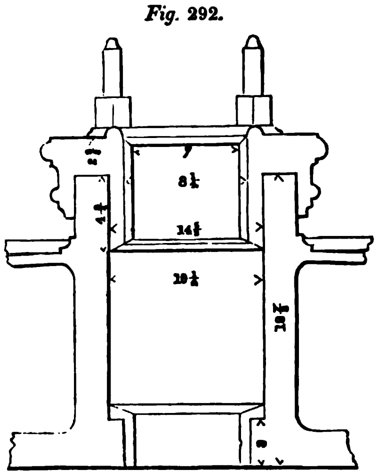
Fig. 291.



TOP OF DON JUAN'S PISTON-ROD.

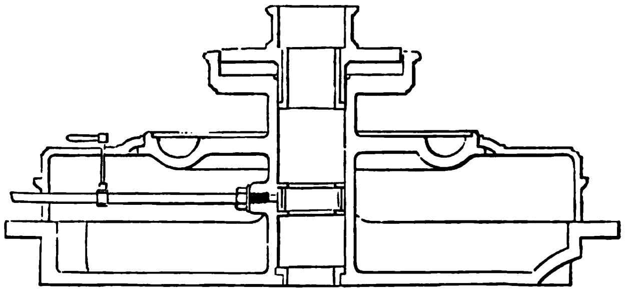
Cylinder Cover. — The cylinder cover in plate of details is cast close, and a few holes are left for taking out the core by, which holes are afterwards plugged up. An annular recess is left in the under side of the cover, for the accommodation of the heads of the piston-bolts. The gland of the stuffing-box is shown on a larger scale on the same plate. *Fig.* 292. represents the stuffing-box of the Don Juan steamer, cylinder 68 inches diameter. This appears to us better than that of the West India packets: there is a great advantage in a deep stuffing-box, especially in the case of vessels intended to perform long voyages. *Fig.* 293. represents the cylinder cover of a Cornish engine. The stuffing-box is provided with a lantern brass, into which steam is admitted by a small pipe. There is packing both above and below the lantern brass, the purpose of which is to prevent any leakage of air by the stuffing-box; for even if the packing be defective, it will be steam that leaks in, which is condensable; and such a leak, though it will increase the consumption of fuel, will not diminish the power of the engine. It is the usual practice to interpose between the cylinder cover and the cylinder flange a gasket-ring as a joint; but a joint of this kind leaks air imperceptibly, and it is better to make the surfaces very true, and to interpose either a ring of sheet-lead or a little red-lead putty. It appears expedient to us that all marine engines should be furnished with steam-jackets, and should also be furnished with spaces in the cylinder-cover and cylinder-bottom for the admission of steam. Large engines, too, we conceive should be fitted with the lantern brass stuffing-boxes. *Fig.* 294. represents the stuffing-box of the Trident, the engines of which are of the oscillating kind by Messrs. Boulton and Watt. The extra depth of this stuffing-box is necessary, to counteract the tendency to wear oval. This tendency, although its existence is undoubted, has not been found to occasion much inconvenience in oscillating engines, although great fears were entertained on that score by the adherents of more antiquated engineering mechanisms. It should be borne in mind also, that even in engines with the ordinary parallel motion the stuffing-box has a tendency to wear oval, which may be perceived if attention be paid to the setting of the parallel motion. If the piston be moved through a stroke, the gland will be found to move easily upon the piston-rod at some points, and be jammed up tight in the stuffing-box at other points of the stroke; inequalities which clearly show the existence of a very sensible deviation from a perfectly vertical motion. The brass dome attached to the gland and embracing the rod, is an excellent addition; it keeps the grease employed to lubricate the rod, from being spilt, and prevents grit and dust from getting into the gland, whereby in common engines the rod is frequently much scratched and injured. Metallic packing in the stuffing-box has been used in some engines, consisting in most instances of one or more rings, cut, sprung out, and slipped upon the piston-rod, before the cross-head is put on, and packed with hemp behind. This species of packing answers very well when the parallel motion is true, and the piston-rod free from scratches, and it accomplishes a material saving of tallow. In some cases a piece of sheet-brass, packed behind with hemp, has been introduced with good effect, a flange, notched to permit the bending, being turned over on the under edge of the brass, to prevent it from slipping up or down with the motion of the rod.

Fig. 292.



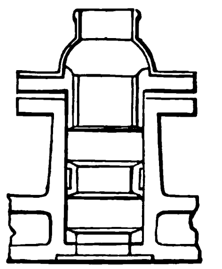
CYLINDER STUFFING-BOX OF DON JUAN.

Fig. 293.



CYLINDER COVER OF CORNISH ENGINE WITH LANTERN BRASS.

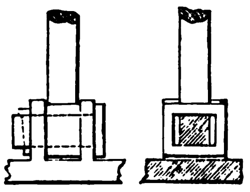
Fig. 294.



STUFFING-BOX OF OSCILLATING ENGINE.
Scale ½ inch = 1 foot.

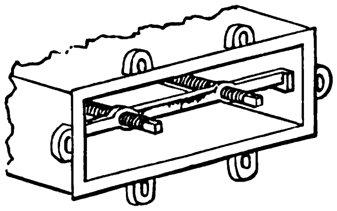
Slide-valve. — The slide-valve represented in the plate of details is that known as the long D. The valve-rod is attached to a cross-bridge in the plane of the under face, and the spring upon the rod is sufficient to allow the valve to be tightened up as the face wears. In short D valves, where the valve-rod is very short, the eye which attaches the valve to the rod has to be made oblong, *fig.* 295., or else the holes of the casing-cover have to be made oval, so as to enable the valve-cover to be advanced nearer to the cylinder, as the valve face wears. The valve-packings are introduced by doors at the back of the valve-casing, and are pressed by blocks, of which one is shown in the same plate as the valve. This block, it will be remarked, is in three pieces, which are tongued to one another; it is pressed forward by means of screws, which pass through a cross-bar extending across the packing-port, *fig.* 296., the ends of which rest in two angular lugs cast therein. The purpose of this bar is to prevent the strain requisite for tightening the packing from being thrown upon the packing-door, which would spring it out, and might cause the joint of the door to leak. In some cases the screws by which the packing is pressed, pass through the door, and are made tight by a jam-nut, with a recess, into which a turned part of the nut enters, as shown in *fig.* 297. — a hemp washer being interposed at the point of contact, and this we think is the preferable practice. In the plate, however, a different plan is shown, which is again represented in *fig.* 298. The packing-screws do not pass through the doors, but are kept short; and opposite to each screw a plug is situated in the packing-door, which has to be withdrawn when the packing is to be tightened. In each of these plugs a small recess is turned out, for the reception of a ring of hemp. This recess is better half-round than square.

Fig. 295.



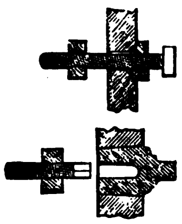
ATTACHMENT OF END OF SHORT D-VALVE ROD.

Fig. 296.



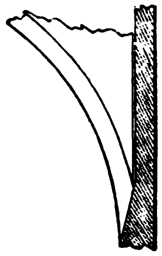
VIEW OF PACKING PORT, CROSS BAR, AND PACKING SCREWS.

Figs. 297, 298.



MODE OF TIGHTENING SLIDE-VALVE PACKING.

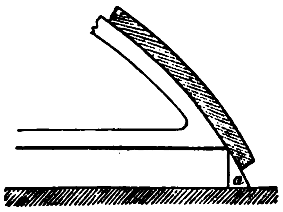
Fig. 299.



METHOD OF TIGHTENING LIDE-VALVE PACKING LATERALLY.

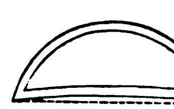
Some packing-blocks are tightened sideways, by screws which are inserted in the sides of the packing-ports; but in the plate the block is tightened by its own wedge-shape point, which presses against another wedge-formed piece, cast on the valve-casing, as will be understood by a reference to *fig.* 299. In some cases the end of the packing abuts upon the cylinder face, but generally it overlaps two or three inches in large engines, and a piece, *a*, *fig.* 300., is cast on each side of the cylinder-port, in continuation of the circle of the valve, to furnish a surface upon which the packing may press. By this expedient the chance of leakage at the corner of the valve is diminished, and the length of the packing need not be adjusted with such critical exactitude as is necessary by the other arrangement. In some engines the packing of the valve is put in like that of a piston, and is pressed down by means of a junk-ring, but that plan is now little resorted to. Metallic packing has been tried in D valves, but only with very moderate success. The kind that has answered best is a piece of sheet brass, thinned at the ends, bent to the shape of the valve, and packed behind with hemp. We believe the D valve will now give place to the equilibrated valve employed by Messrs. Penn, and of which we have already given a description at page 199.

Fig. 300.



OVERLAP OF VALVE-PACKING.

Fig. 301.



DISTORTION OF SLIDE-VALVE BY UNEQUAL EXPANSION.

We have experienced a good deal of trouble with every modification of valve faces; but cast iron working upon cast iron is perhaps the best combination yet introduced. The usual practice is to pin brass faces on the cylinder, allowing the valve to retain its cast-iron face. Some makers employ brass valves, and others pin brass on the valves leaving the cylinder with a cast-iron face. Speculum metal and steel have been tried for the cylinder faces, but only with moderate success. In some cases the brass gets into ruts; but the most prevalent affection is a degradation of the iron, owing to the action of the steam, and the face assuming a granular appearance, something like loaf sugar. This action shows itself only at particular spots, and chiefly about the angles of the port, or valve face. At first the action is slow; but, once the steam has worked a passage for itself, the cutting away becomes very rapid, and in a short time it will be impossible to prevent the engine from heating when stopped, owing to the leakage of steam through the valve into the condenser. However truly the D valve may be formed at first, the face will become slightly hollow by the application of heat, as the circular will expand more than the straight part, and the packing resists the enlargement of the circle. The cross-section will therefore assume something of the form shown in *fig.* 301, where the dotted line represents the original position of the face; and on examining a valve newly put in action, it will generally be found that it presses hardest on the tails. The face therefore should be made slightly rounded in the manufacture; and if the engine is a large one, the cylinder must not be faced when lying on its back, unless it has been wedged up to the form it assumes when standing on end, else the partial collapse of the cylinder will cause the face to become untrue. Copper steam-pipes seem to have some galvanic action on valve faces, and malleable iron pipes have sometimes been substituted; but they are speedily worn out by oxidation, and the scales of rust which are carried on by the steam, scratch the valves and cylinders, so that the use of copper pipes is the least evil. The valve-rod in that part opposite to the steam-port is often much wasted by the steam; it therefore appears expedient to surround it by a copper pipe where an injurious action is to be apprehended. The valve-casing shown in the plates is made close at the bottom, the exhaustion being accomplished by the upper eduction-pipe. In cases in which exhaustion is performed from below, it is expedient to cast two projections on the sole-plate, to prevent the valve from falling down inconveniently far when the valve links are taken off. There is no expansion joint introduced in the valve-casing of these engines, which is a serious defect, as the steam gains admission to the valve-casing before it can enter the cylinder, and the joints are damaged, and in some cases the cylinder is cracked, by the inequality of expansion of the cylinder and valve-casing.

In facing a valve recourse is had to the use of a face plate, to ensure the accuracy of the work. To ascertain whether the face plate bears equally, smear it over with a little red ochre and oil, and move the face plate slightly, which will fix the colour upon the prominent points. This operation is to be repeated frequently, and as the work advances, the quantity of colouring matter is to be diminished, until finally it is spread over the face plate in a thin film, which only dims the brightness of the plate. The surfaces at this stage must be rubbed firmly together to make the points of contact visible, and the higher points will become slightly clouded, while the other parts are left more or less in shade. If too small a quantity of colouring matter be used at first, it will be difficult to form a just conception of the general state of the surface, as the prominent points will alone be indicated, whereas the use of a large quantity of colouring matter in the latter stages would destroy the delicacy of the test the face plate affords. The scraping tool should be of the best steel, and should be carefully sharpened at short intervals on a Turkey stone, so as to maintain a fine edge. A flat file bent, and sharpened at the end, makes an eligible scraper for the first stages; and a three-cornered file, sharpened at all the corners, is the best instrument for finishing the operation. The number of bearing points desirable on the surface of the work depends on the use to which it is to be applied, but in any case the bearing points should be distributed equally over the surface. Great care must be taken in fitting valve-faces that the valve be not made conical: unless the back be exactly parallel with the face, it will be impossible to keep the packing from being rapidly cut away. When the valve is laid upon the face-plate, the back must be made quite fair along the whole length, by draw-filing, according to the indications of a straight edge; and the distance from the face to the extreme height of the back must be made identical at each extremity. Should a hole occur either in the valve, in the cylinder, or any other part where the surface requires to be smooth, it may be plugged up with a piece of cast-iron as nearly as possible of the same texture. Bore out the faulty part, and afterwards widen the hole with an eccentric drill, so that it will be of the least diameter at the mouth. The hole may go more than half through the iron: fit then a plug of cast-iron roughly by filing, and hammer it into the hole, whereby the plug will become rivetted in, and its surface may then be filed smooth. Square pieces may be let in after the same fashion, the hole being made dovetailed, and the pieces thus fitted will never come out.

Brass faces are put upon valves or cylinders by means of small brass screws, tapped into the iron with conical necks for the retention of the brass: they are screwed in by means of a square head, which, when the screw is in its place, is cut off and filed smooth. In some cases the face is made of extra thickness, and a rim not so thick runs round it, forming a step or recess for the reception of brass rivets, the heads of which are clear of the face.

Air-pump.—The air-pump is attached to the sole-plate by a rust faucit joint, which is preferable to a rust flange joint, as the salt-water eats away the heads of the bolts, unless they are copper; and if they are copper, they waste the iron. The oil and grease which fall from the crank-pin upon the sole-plate, deoxidise the rust of a flange joint, whereas with a faucit joint, suitably made, they cannot remain in the same intimate contact. Short steel keys should be driven into the faucit in several places before the joint is made, but they should not rise to the top of the faucit so as to divide the joint into segments.

The air-pump bucket is made with a junk-ring, whereby the packing of the bucket may be easily screwed down. The valve is of the spindle or pot-lid kind. The foot and delivery are of the flap or hanging kind. These valves all make a considerable noise in working, and are objectionable in many ways. Valves of the same construction as those known as Harvey and West's, which are similar to those shown in *fig.* 242. have been employed with advantage by Messrs. Rennie; and valves on Belidor's construction, which is in effect that of a throttle-valve hung off the centre, were some years ago proposed by us for the delivery and foot-valves. Some delivery-valve seats are bolted into the mouth of the air-pump, apparently in the conviction that the pump-bucket never requires to be looked at. If delivery-valves be put in the mouth of the air-pump at all, the best mode of fixing them appears to be that adopted by Messrs. Maudslay. The top of the pump-barrel is made quite fair across, and upon this flat surface a plate containing the delivery-valve is set, there being a small ledge all round to keep it steady. Between the bottom of the stuffing-box of the pump cover and the eye of the valve-seat, a short pipe extends, encircling the pump-rod, its lower end checked into the eye of the valve-seat, and its upper end widening out to form the bottom of the stuffing-box of the pump-cover. Upon the top of this pipe some screws press, which are accessible from the top of the stuffing-box gland, and the packing also aids in keeping down the pipe, the function of which is to retain the valve-seat in its place. When the pump-bucket has to be examined the valve-seat may be slung with the cover so as to come up with the same purchase. For the bucket-valves Messrs. Maudslay employ two or more concentric ring-valves, with a small lift. These valves have given a good deal of trouble, in consequence of the frequent fracture of the bolts which guide and confine the rings; but their principle appears to us superior to that of any of the other air-pump valves at present in common use, with the exception of the equilibrated-valve, known as Harvey and West's, in which it is preferable that the face should fall in a groove filled with end-wood. It would not be difficult to make this groove so that the water would have to be forced out of it during the descent of the valve, whereby the shock would be still further diminished. It would be preferable, however, if all these valves could be discarded in favour of a slide-valve, which it appears to us might be applied to the air-pump with much advantage.

The air-pump bucket and valves are all of brass, and the chamber of the pump is lined with copper. It is now a common practice to make the chamber of the air-pump wholly of brass, whereby a single boring suffices. When a copper lining is used, the pump is first bored out, and a bent sheet of copper is introduced, which is made accurately to fill the place, by hammering the copper on the inside. Muntz's metal is sometimes used instead of copper, and Muntz's metal air-pump rods are now as generally used as copper rods or iron rods covered with brass. Iron rods covered with brass are not to be commended; they generally are wasted away where the bottom cone fits into the bucket-eye, and if the casing be at all porous, the water will sometimes insinuate itself between the casing and the rod, and eat away the iron. If iron rods covered with brass be used, the brass-casing should come some distance into the bucket-eye; the cutter should be of brass, and a brass washer should cover the under side of the eye, so as to defend the end of the rod from the salt water. Rods of Muntz's metal are, probably, on the whole to be preferred; and it is a good practice to put a nut on the top of the rod to secure it more firmly in the cross-head eye. The part which fits into the cross-head eye should have more taper when made of copper or brass than when made of iron; as if the taper be small, the rod may get staved into the eye, whereby it will be so firmly fixed as to make its detachment a difficult operation. Metallic packing has in some instances been employed in air-pump buckets, but its success has not been such as to lead to its further adoption.

Sole-plate and Condenser.—Every marine engine, of the side-lever kind, should be constructed with a sole-plate; and we think it the best way that the condenser be cast upon the sole-plate. Engines unfurnished with sole-plates, and with joints between the valve-casing and condenser below the level of the keelsons, are extremely objectionable. Those joints, either from the working of the ship—the movement of the cylinder or condenser—the deoxidising effect of the oil spilt about the machinery—or the combination of all these causes—will be sure, sooner or later, to become leaky; and it is almost impossible to remake or effectually staunch them. Messrs. Maudslay and Co., in their West India mail packet engines, bolted the condenser to the *under*-side of the sole-plate; by which expedient the rust-joints are preserved, in a great measure, from the action of the grease, and from any strain or vibration consequent upon the yielding of the condenser or cylinder. Messrs. Miller and Co. adopted the same arrangement of condenser, but *cast* the condenser upon the sole-plate.

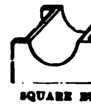
There are very few of the engines made in Scotland in which the condenser is not cast upon the sole-plate; and in almost all of them the greater part of the condenser is situated above the sole-plate, and the main-centre passes through it. The height of the condenser, in this arrangement, has the advantage of enabling the air-pump to drain it of water very effectually; but the same object is accomplishable by the use of a very large eduction-pipe immediately behind the valve-casing into which the injection-water is admitted, and which thus becomes, in effect, a tall condenser. This latter is the arrangement of Messrs. Maudslay and Messrs. Miller. It has the advantage of leaving the space usually occupied above the sole-plate by the condenser, free and unperplexed by any species of machinery except the main-centre, which is supported by pillow-blocks resting or cast on the sole-plate.

The practice of passing the main-centre through the condenser, either with or without a pipe, is objectionable. A pipe is calculated to make the sides of the condenser crack by unequal contraction, and the absence of a pipe endangers a leakage of air round the main-centre joint. The keys employed to fix the main-centre will sometimes occasion trouble, from becoming loose; and, in some instances, we have known a main-centre boss to be split, from the keys being driven too hard. It all cases the thickness of metal requisite in the condenser sides for resisting the strain of the main-centre, will make the sides more liable to crack, in consequence of being suddenly cooled. Upon the whole, the practice of securing the main-centres by plummer-blocks appears greatly preferable: when the main-centre is made to pass through the condenser, the hole should be bored out, and the main-centre ground in with a little taper. It is the usual practice in engines which have the main-centre passing through the condenser, to set the hot well on the top of the condenser, and this is the arrangement in the engines of which we have given the details. A part of the hot well is divided off, to serve as an eduction-passage for the conveyance of the steam from the superior part of the valve-casing. By this arrangement there is no danger of water running from the condenser back into the cylinder. Projections are cast in the foot-valve passage for the reception of the foot-valve seat, by means of which it is keyed into its place; and similar projections are cast in the mouth of the air-pump for the reception of the delivery-valve.

There does not appear to be any manhole-door to the condenser in this engine, which is in our eyes a defect. It would have been easy to make a manhole in the curved nozzle leading from the air-pump to the hot well: a door in that situation would have been easy of access from the hot well manhole, and it would have always been covered with water when the engine was at work, so that a leakage of air could not have taken place. The injection rose-pipe runs across the condenser, near the mouth of the eduction-pipe. A cock, by which water may be injected from the bilge should the vessel spring a leak, is universally employed in marine engines, and is shown in the sectional drawing of the engines of which we give the details, dotted in. This cock should never be furnished with a rose within the condenser, and should never be joined on to the injection-pipe proceeding from the sea. We have known various cases in which a vessel has been nearly lost from the internal roses of the bilge injection becoming choked up with refuse drawn out of the bilge, and which, but for those roses, would have passed into the condenser and been delivered by the air-pump without creating any obstruction.

Framing.—Cast-iron framing is now given up in marine engines, and malleable iron framing alone is employed. Of malleable iron framing as applicable to the side-lever engine, we have given a specimen in the engines of the City of London steamer; and of cast iron framing it is needless, under the circumstances, to say much. It is a bad plan, in our judgment, to attach the diagonal stay to the hot well, as is sometimes done, as the working of the stay breaks the hot-well joint. It is a bad plan, too, to attach the framing to the sides of the ship, as the working of the ship in a sea will strain and may break it. In iron steamers a plan now prevails of running the deep beams before and abaft the crank-hatch (which are also made of iron) through the ship's side, joining the extremities of those beams by curved cross-beams, on which the shaft plummer-blocks are made to rest The paddle-wheel, by this plan, is overhung, and the whole of the arms radiate from a triple centre. A very substantial framing may be made by adopting this arrangement, and it is one which is applicable in the case of direct-action engines as well as in those on the side-lever plan. The brasses of the paddle-shaft plummer-blocks should not be made with fitting strips on the backs, but the whole of their exterior should be planed, and the interior of the plummer-blocks should also be planed for their reception. Brasses fitted with fitting strips soon wear slack sideways. Octagonal bottom brasses are not so good as those which are square, as they cannot be lined up so conveniently if the shaft gets out of truth. Square-bottom brasses, with flanges, as shown in *fig.* 302., we have found preferable to any other variety.

Fig. 302.



SQUARE BUSH.

Side-lever.—The drawing we have given of the side-lever will sufficiently explain its general form and dimensions. In some of the more recent side-lever engines, the side-levers are made of malleable iron, each lever being composed of two plates, set on edge, the length of the bearings apart from each other. The studs in the side-lever should be steeled and should be of larger dimensions than is necessary for strength; as if they wear oval, they are likely to burst the side-rod or cross-tail straps, when the brasses are tightened up. Unless the main centre journals be made spheroidal, there should always be large collars on the main-centre, against which the side-levers may press, so as to prevent lateral play; and the washers on the main-centre ends should be capable of being tightened up against the brasses of the side-lever eye. Without this precaution, the engines will jerk most disagreeably sideways in a sea-way when the brasses come to be at all worn.

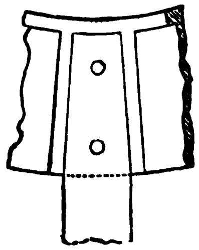
Cross Heads and Tails, Side and Connecting Rods.—The parallel motion, it will be remarked in the drawings of details, is attached to the cross-head, which is in our eyes the best arrangement, if a parallel motion be used; but parallel motions are now falling into disfavour, and guides are taking their place. The side-rod eye is fitted with a conical bush, with a spiral cut in it, so that it may be tightened upon the cross-head journal, by means of a washer drawn in by a screw. In some cases the side-rod eye is fitted with an octagonal brass, tightened by a cutter beneath the under portion; and in other cases the brass is round, and the upper portion is pressed down by means of a screw, which is made hollow, and serves also as an oil cup. The upper piece is such as would require to be cut out of the brass, in order to permit the journal to come out without being shifted on end; and the sliding joints of the bush are rebated, to prevent end-play. In the manufacture of brasses of this kind, the pieces are first fitted and soldered together; they are then bored and turned; and finally the soldering is loosened by the application of heat. The cross-tail butts are generally ground on to their places, and the end of the cross-tail rivetted over on them, a round steel pin being afterwards introduced, half into the cross-tail, and half into the butt. In some cases, however, they are put on hot, as practised in the case of cranks; and in the specimen before us a washer is substituted for the rivetting of the end. In all cases in which an eye is put on hot against a collar, the eye should be recessed for the reception of a small portion of the collar; as we have already mentioned when speaking of the cranks of land engines, as the eye in contracting sideways will leave a space between the collar and the eye, which, by this means, will not be discernible. The connecting-rod is made with a strap to embrace the crank-pin as is the usual practice. The connecting-rod top of most of Messrs. Penn's and Messrs. Maudslay's engines are made after the same fashion as the Black Eagle's. Connecting-rods made in this way should always have a malleable iron cap above the upper brass instead of having the cap and upper brass made in a piece. If the crank-pin heats, the brass cap will probably be cracked, and cases might be mentioned in which vessels have been nearly lost from such an occurrence.

Cranks, Eccentrics, Shafts, and Paddles.—The cranks and shafts of marine engines are now always made of wrought iron. The crank is shrunk on the shaft hot, and a strong square key is then driven in at the part nearest the web, so as to obviate the weakening of the eye. The crank-pin is fixed in the intermediate crank, and is loose in the eye of the paddle crank, which is fitted with a bush, upon which the rounded end of the crank-pin bears. The end of the crank-pin, fitting into the eye of the intermediate crank, is made conical, and is drawn into its place by a cutter passing through both pin and eye. The rounded end of the pin enables the paddle shaft to fall at the outer end—as it always does—without breaking the pin. In some cases a drag-link is used instead of the rounded pin, but drag-links are not now much in fashion. A very good method of fixing the crank-pin into the eye is that which was adopted in the Don Juan steamer. It consists in the application of a strong washer over the crank-eye, with a hole in the centre, through which a stout bolt passes tapped into the pin. The washer is indented a little into the crank-eye, so as to obviate any tendency to move laterally. This plan we know, from our own experience, to be a very effectual one: it is unattended with any more trouble than if the pin were rivetted in, and it admits of the pin being taken out, by merely unscrewing the bolt of the washer. The end of the pin inserted in the loose eye is of course made spheroidal, so as to permit the outer end of the shaft to drop a little, without breaking the pin. The pin is steeled on both sides of this spheroidal part, and bears against two dovetailed steel plates. The plate situate on the *backing* side was, in the case of the Don Juan, tightened by means of a screw passing through the crank-eye. The web of the crank was made thicker and narrower than usual, the intention of the makers being, that the web should be capable of resisting the twist occasioned by the overhang of the crank-pin more effectually than is done in the case of cranks whose shape is regulated by the supposition that the crank-pin does not overhang at all. There is more plausibility than soundness in this reasoning; the fact being that the strength given for the single purpose of overcoming the leverage, is more than sufficient to withstand the twist. The crank-pin must be fitted very accurately into the crank-eye, else it will be very liable to be broken. The crank-pin should always be larger in diameter than is necessary for strength, for the purpose of keeping the journal from heating. The dimensions given in our tables will be found to answer very well, and they are slightly in excess of the common proportions.

We do not intend, in the present work, to go into the subject of steam navigation, yet we may here set down a few remarks about paddle-wheels, which cannot well be severed from the subject of the engine. The best plan of making the centres is with square eyes, and each centre should be secured in its place by means of eight *thick* keys. The shaft should be burred up against the heads of these keys with a chisel, so as to prevent the keys from coming back of their own accord. If the keys are wanted to be driven back, this burr must be cut off, and the keys, if made thick and of the right taper, may then be started without difficulty. The shaft must of course be forged with square projections on it, so as to be suitable for the application of centres with square eyes. Messrs. Maudslay and Co. bore out their paddle-centres and turn a seat for them on the shaft, afterwards fixing them on the shaft with a single key. The plan is objectionable for two reasons—it is insecure when new, and when old is irremovable. One of the West India mail vessels, by Messrs. Maudslay, was almost disabled from this cause on the first voyage, the key on the shaft having slackened, and the centre having consequently turned round; and in some of the older vessels by the same makers, lately under repair at Woolwich, the centres had to be broken off, for they could not be got off in any other way. With this plan of centre we have often known the centres to shift: in one case, the wheel on the weather side was forced against the side of the ship, and the floats, in their revolution, cut deeply into the outside planking. The plan of making round bosses on the shaft, and fixing the centres with four keys, as shown in our plates of details, is also objectionable on the ground of insecurity.

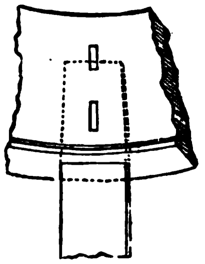
The general practice among the London engineers is to fix the paddle-arms at the centre to a plate by means of bolts, *fig.* 303., a projection being placed upon the plates on each side of the arm, to prevent lateral motion.

Fig. 303.



ATTACHMENT OF ARM TO PADDLE CENTRE.

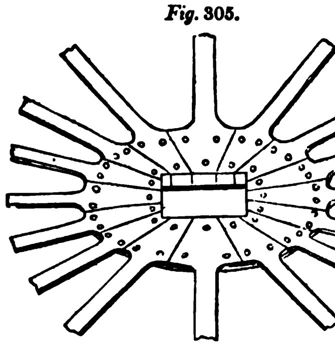
Fig. 304.



INSERTION OF ARM IN PADDLE CENTRE.

We have found this method to be inferior in durability to that adopted in the Clyde, *fig.* 304., in which each arm is fitted into a socket by means of a cutter, a small hole being left opposite to the end of each arm, whereby the arm may be forced back by a drift. A preferable way would be to form the paddle-centre out of the arms themselves, by widening them at the head until they touch one another, *fig.* 305., and then applying a boiler-plate upon one side, and rivetting the arms firmly to it. If this plan be adopted, it will be expedient to swell the tops of the uncovered side at the part nearest the centre, so as to increase the length of bearing for the keys which secure the centre to the shaft. In the manufacture of this centre the heads of the arms would first be forged, then planed on the edges and fitted together on the plate. The holes would then be bored for the rivets, temporary bolts fitted into them, and the key-seats cut and the ends of the arms pared in the slotting-machine. Finally, the arms would be welded on to the heads, and the various parts of the wheel rivetted together.

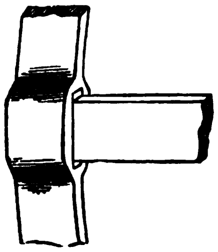
Fig. 305.



PADDLE CENTRE.

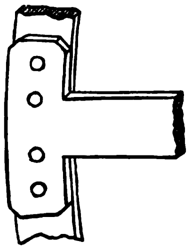
Most of the London engineers join the paddle-arms to the outer ring, by means of bolts, but we cannot say that we approve the plan, for those bolts, after a time, generally become slack sideways, and a constant working of the parts of the wheel goes on in consequence. Some engineers form the part of the outer ring opposite the arm into a mortice, *fig.* 306., and they wedge the arms tight in the hole, by wedges driven in on each side. But the plan is an expensive one, and not satisfactory, as the wedges work loose even though rivetted over at the point. The best mode that we have met with is the plan for the most part practised in the Clyde, *fig.* 307., of making the arm with a long T head, and rivetting the cross piece to the outer ring with a number of rivets, not of the largest size, which would weaken the outer ring too much. The best way of securing the inner rings to the arms is by means of lugs, *fig.* 308., welded on the arms, and to which the rings are rivetted.

Fig. 306.



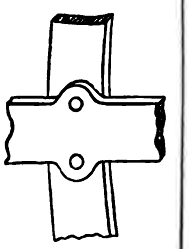
MORTICE ATTACHMENT OF PADDLE-ARM.

Fig. 307.



ATTACHMENT OF PADDLE-ARM TO OUTER RING.

Fig. 308.



ATTACHMENT OF PADDLE-ARM TO INNER RING.

Paddle-floats are usually made either of elm or of pine: if of the former, the common thickness for large sea-going vessels is about 2½ inches; if of the latter, 3 inches. They should have plates on *both* sides, else the paddle-arms will be very liable to cut into the wood, and the iron of the arms will be rapidly wasted. When the floats have been fresh put on, they must be screwed up several times before they come to a bearing. If this be not done, the bolts will be sure to get slack at sea, and all the floats on the weather side may be washed off, as once occurred to the British Queen, on the next voyage after the floats had been removed to allow the vessel to go into dock. It is a good plan to give the thread of the paddle-bolts a nick with a chisel, after the nut has been screwed up, which will prevent the nut from turning back. The floats should not be notched out, to allow of their projection beyond the outer ring; as, if the sides of the notch be in contact with the outer ring, the ring is soon eaten away in that part, and the projecting part of the float, being unsupported, is liable to be broken off. It is usual to put a steel plate at each end of the paddle-shaft, tightened with a key, to prevent end-play when the vessel rolls, but the arrangement is precarious, and insufficient. Messrs. Maudslay make their paddle-shaft bearings with very large fillets in the corner, with the view of diminishing the evil; and Mr. R. Napier causes the crank-eyes of both paddle and intermediate cranks to bear sideways against the brasses of the plummer-blocks. It would be preferable, we conceive, to make the bearings of the crank-shafts spheroidal, and, indeed, it would be an improvement we think, if most of the bearings about the engine were to be made in the same fashion. The spheroidal form would not only prevent end-play, but would keep the oil from running out at the ends of the bearings. The loose end of the crank-pin should be made not spheroidal, but consisting of a portion of a sphere, and a brass bush might then be fitted into the crank-eye, that would completely encase the ball of the pin, and yet permit the outer end of the paddle-shaft to fall without straining the pin, the bush being at the same time susceptible of a slight end-motion. This arrangement is far preferable, we conceive, to that of making the pin bear upon a single point, as is the common practice. There is an inconvenient amount of wear on the pin, which involves a backlash in the eye, and the point of contact sometimes heats and screeches, unless the eye be kept well supplied with tallow.

Disengaging Paddle-Wheels. — Many plans have been contrived for disengaging the paddle-wheels of steamers, so as to enable one paddle to be worked without the other, or both paddles to be thrown out of gear, so as to revolve loosely when the vessel is under sail. The best of these expedients that we are acquainted with is that represented in *figs.* 309, 310., where A is the paddle-shaft; B, a cast-iron disc keyed thereon; C, a wrought iron strap surrounding the disc, lined with brass; D, a brass cushion with a tightening key for producing friction, by bringing the cushion in contact with the disc; F, the brass lining of the wrought iron strap, excepting that portion occupied by the cushion; *f f f*, screws by which the brass lining is held to the strap. A few blows of a hammer on the key D will connect or disconnect the paddle-shaft, even when the engines are at full speed.

Fig. 309.

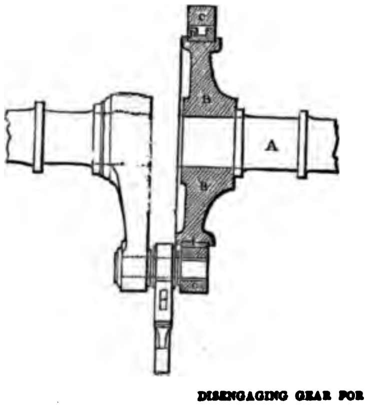
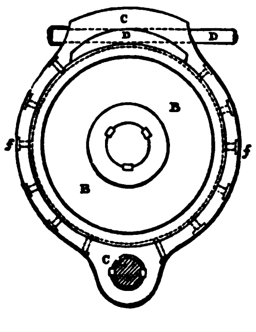


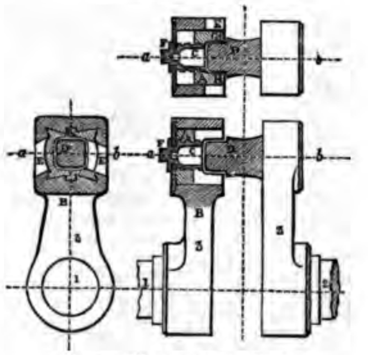
Fig. 310.



DISENGAGING GEAR FOR PADDLE.

Messrs. Maudslay's method of disconnecting is to shift the shaft on end by suitable gear, until the crank-pin leaves the crank-eye. Messrs. Miller's method is to put a clutch on the shaft, which catches into the paddle centre —the whole of the three centres being combined into one diverging one, which runs loose on the shaft. A method contrived by Mr. Grantham is represented in *figs.* 311, 312, 313., where A is a moveable bush in the paddle crank eye; B, the crank; C, a screw for moving in or out the bush; D, crank pin; E, slot in the crank eye to permit the pin to pass in the revolution of the crank, except when the pin bush is moved out to engage it; F, square head of screw C; G, H, the bush engaged with the crank pin. It is obvious that by screwing the bush out or in, the crank pin is either engaged with or disengaged from the paddle. In Messrs. Seaward's engines a method of disengaging almost identical with this is sometimes employed.

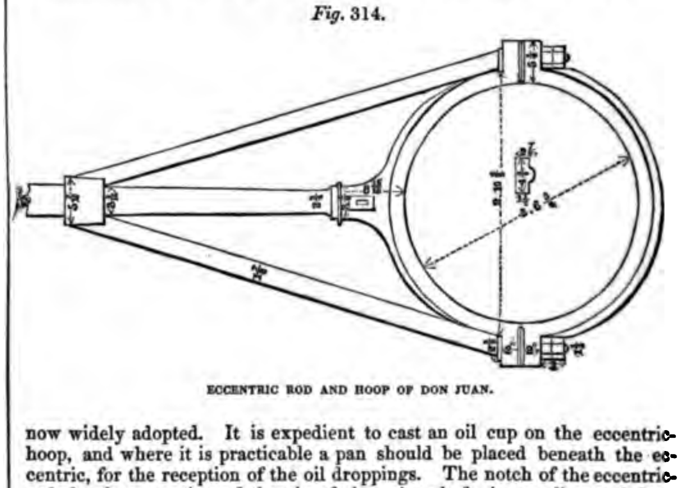
Figs. 311, 312, 313.



GRANTHAM'S DISENGAGING GEAR.

Eccentrics. — The eccentrics of marine engines are always put on in two pieces; they are almost always loose on the shaft, and are always capable of backing. The manner in which that shown in our plates of details is made, is a common one. The eccentric is loose upon the shaft, and is furnished with a back balance and catches, and the halves are put together with rebated joints, to keep them from separating laterally; and they are prevented from sliding out by round steel pins, each ground into both halves. We think square keys would be preferable to round pins in this arrangement, as the pins tend to wedge the jaws of the eccentric asunder. In some cases the halves of the eccentric are bolted together by means of flanges. The eccentric-rod shown in the plates of details is not a particularly neat one. The eccentric-rod of the Don Juan is represented in *fig.* 314., and that form is now widely adopted. It is expedient to cast an oil cup on the eccentric-hoop, and where it is practicable a pan should be placed beneath the eccentric, for the reception of the oil droppings. The notch of the eccentric-rod, for the reception of the pin of the valve-shaft, is usually steeled, to prevent inconvenient wear; for when the sides of the notch wear, the valve movement is not only disturbed, but it is very difficult to throw the eccentric-rod out of gear. It is found to be preferable, however, to fit this notch with a brass bush, *fig.* 315., for the wear is then less rapid, and it is an easy thing to replace this bush with another when it becomes worn. The

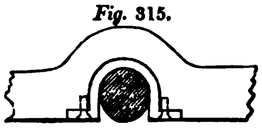
Fig. 314.



ECCENTRIC ROD AND HOOP OF DON JUAN.

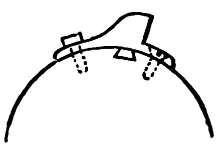
eccentric catches shown in the plates are the kind usually employed, but catches of this kind sometimes break off at the first bolt-hole, and it is preferable either to have a bolt in advance of the catch-face, as in *fig.* 316., or to have a hoop encircling the shaft, with the catches welded on it, the hoop itself being fixed by bolts or a key. This hoop may either be put on before the cranks in one piece, or afterwards in two pieces, as shown in *fig.* 317., which represents the hoop employed in the Don Juan steamer.

Fig. 315.



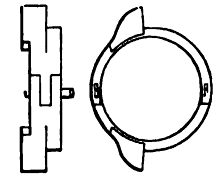
BUSH OF ECCENTRIC ROD NOTCH.

Fig. 316.



ECCENTRIC CATCH.

Fig. 317.



ECCENTRIC CATCH OF DON JUAN.

The expansion cam is figured in the plate; it is put on the shaft in two pieces, which are fastened to each other by means of four bolts passing through lugs, and is fixed to the shaft by keys. A roller at one end of a bell-crank, which is connected with the expansion-valve, presses against the cam, so that the motion of the lever will work the valve. The roller is kept against the cam by a weight on a lever attached to the same shaft. If the cam were concentric with the shaft, the lever which presses upon it would remain stationary, and also the expansion-valve; but by the projection upon the cam, the end of the lever receives a reciprocating motion, which is communicated to the valve. The position of this projection determines the point in relation to the stroke at which the valve is opened, and the extent of the projection determines the duration of opening. The time at which the valve should begin to open is the same under almost all circumstances; but the duration of its opening varies with the amount of expansion desired. In order to obtain this variable expansion, there are several projections made upon the cam, each of which gives a different degree or *grade*, as it is usually called, of expansion. These grades begin at the same point on the cam, but are of different lengths, so that they would begin to move the lever at the same time, but would differ in the time of returning it to its original position. The change of expansion is effected by moving the roller on to the desired grade: there are seven different grades in the West India steamers. The expansion-valve is of the kind used in the Cornish engines, and known as the equilibrium valve. Of the valve shafts and links, parallel-motion rods, and other similar details, it is needless here to speak, as there is nothing of difficulty connected with those parts, and the plates make their arrangement sufficiently intelligible.

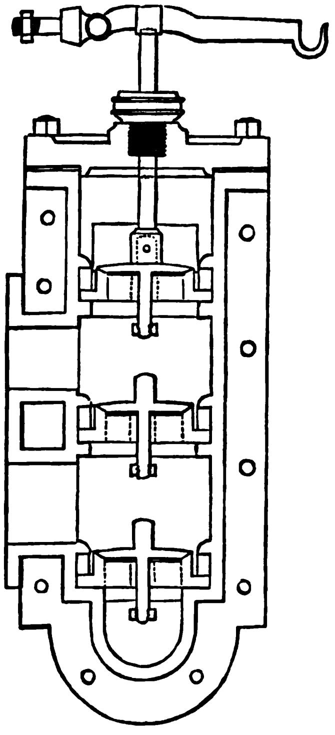
Starting Gear.—The best starting gear that we are acquainted with is Stephenson's link motion, which will be described in our remarks respecting details of locomotives. This combination obviates the necessity of throwing the engines out of gear at all; and full speed a-head may be changed instantaneously into full speed astern, and without stopping the engines. Messrs. Rennie have introduced this species of starting gear into the Samson and some other steam vessels with the most satisfactory results; and it appears likely to become general, at least in valves where there is little lap. In our plates of details the valve is moved by means of a lever, and the eccentric-rod is thrown out of gear by means of a pulley on the end of a lever, which, when raised, forces the pulley against the under side of the rod, and lifts it out of the notch. The act of raising this pulley depresses another pulley on a lever fixed upon the same shaft, and enables another rod in connection with the starting handle to fall into gear, the intention being, that when the eccentric-rod is in gear, the starting handle shall be without motion, as its swinging would be inconvenient and dangerous if worked by the engine. This plan of preventing the starting-handle and the eccentric-rod from being in gear at the same time has now come into general use. The method adopted by Mr. Robert Napier in the Precursor is a very elegant one: it consists in the use of an eccentric-stud for supporting the lever which carries the roller; and the act of moving this lever, so as to enable the eccentric-rod to fall into gear, draws back the pinion of the starting-shaft out of the sector, with which it is engaged. Instead of a lever, the starting-shaft in this case is moved by a wheel similar to a steering wheel of a ship. Similar wheels may be seen in several of the examples given in the folio plate of direct-action engines, and their use is now nearly universal.

Brine Pumps.—Pumps for changing the water in marine engine boilers, so as to prevent the salt water from reaching an inconvenient degree of saturation, were first applied by Messrs. Boulton and Watt to the City of Edinburgh steamer, at the suggestion of Mr. Brown and with the approval of Mr. Watt. Mr. Brown had accompanied the vessel on her first voyage from London to Edinburgh, and found that though the engine operated satisfactorily, the water in the boiler acquired such an injurious degree of concentration, that the furnaces began to get red hot. He therefore requested the captain to stop the vessel, and directed the engineer to take off the mud-hole doors and allow the water in the boilers to run into the ship; the boiler was then refilled with water from the sea, and the vessel proceeded on her voyage. Mr. Brown then devised pumps for removing the super-salted water from the boiler without interruption. These pumps are still used by Messrs. Boulton and Watt, and their use is now very general. In the engines of the Centaur represented in the plate of direct action engines, the brine pumps are set on each side of the feed pump and are wrought with it off the air pump cross-head. In some cases the feed water is sent into a vessel called a refrigerator, as has already been mentioned at page 83., through which the super-salted water proceeding from the boiler to the brine pump is conducted in a multitude of small pipes, —the intention of the arrangement being to economise heat by communicating the heat of the super-salted water to the feed. But the amount of heat thus saved is, as we have already explained, exceedingly unimportant, and the refrigerators are not only expensive to construct, but are very liable to be choked up by deposit. They thus become a source of danger, as the engineer is led to confide in an expedient which may deceive him, while he believes it to be in effective operation. The valves of brine pumps require to be loaded sufficiently to counteract the pressure of the steam, and of the head of water in the boiler. If brine pumps be used, it appears preferable to use them without the refrigerator; they then become equivalent to a continuous blowing off, but the pipes are less liable to choke, and there is no blowing off while the engines are at rest.

Sea water contains about $\frac{1}{33}$ its weight of salt, and its specific gravity is increased by boiling until it contains $\frac{12}{33}$ of salt, which is the point of saturation, and the water will not then hold more salt in solution. As the water is more concentrated, it requires a higher temperature to make it boil. The boiling point of sea water which has $\frac{1}{33}$ of salt, is 213.2°; with $\frac{2}{33}$, 214.4°; with $\frac{3}{33}$, 215.5°; with $\frac{4}{33}$, 216.7°; with $\frac{5}{33}$, 217.9°; with $\frac{6}{33}$, 219°; with $\frac{7}{33}$, 220.2°; with $\frac{8}{33}$, 221.4°; with $\frac{9}{33}$, 222.5°; with $\frac{10}{33}$, 223.7°; with $\frac{11}{33}$, 224.9°; and saturated water 226°. These are the boiling points in the open air; in a steam boiler, where the pressure of steam is always above the pressure of the atmosphere, the boiling points will be correspondingly higher, but with any uniform pressure of steam in the boiler it is possible to make the thermometer an index of the saltness of the water. If the water be maintained at a concentration of $\frac{4}{33}$, or if about one fourth of the water be withdrawn from the boiler by the brine pumps that is forced in by the feed pumps, very little deposit will collect within the boiler. The quantity of fuel wasted by blowing off this quantity of water, cannot, it is clear, be considerable, and there should not be less blown off. Of every 4 cubic feet of water entering the boiler from the hot well, 3 passes off in steam and 1 in brine. The temperature of the hot well being 100°, the heat imparted to the water to raise it into steam, may be represented by $1112° \times 3 = 3336$, while the heat contained in the brine is 112° or rather less, the specific heat of brine being less than that of fresh water, and $3336 \div 112 = 29$, so that about $\frac{1}{30}$th of the heat passes out in the super-salted water when large blowing off is practised. A much larger quantity of heat than this goes to waste if there be any material accumulation of scale upon the flues, and engineers will therefore see that there is no economy in penurious blowing off.

Pumps, Cocks, and Pipes.—In the plates of details the feed-pump plunger is shown with a screw at the bottom, for the extraction of the core, but it appears preferable to extract the core out of a hole in the top, which may be adapted for the reception of the pump-rod. There should be a considerable clearance between the bottom of the plunger and the bottom of the pump-chamber, as otherwise the bottom of the chamber may be knocked out, should coal-dust or any other foreign substance gain admission, as it probably would do, if there were any injecting from the bilge. Messrs. Maudslay make the feed and bilge-pump plungers serve as guides to the air-pump cross-head, the pump-rods being continued upwards and working through eyes in the framing. We do not see any objection to this arrangement, if the stuffing-boxes be made deep: when separate guide-rods are used with eyes in the cross-head, those eyes should be fitted with stuffing-boxes, to diminish the wear, and the guides should be made very strong, for the same reason. The valves of the feed-pump are most conveniently arranged in a chest, which may be attached in any accessible position to the side of the hot-well. An arrangement of this kind is shown in the plate of details and in *fig.* 318., which represents the feed-chest of the Don Juan steamer. Of the two side nozzles, the lower one leads to the pump and the upper one to the boiler. The pipe leading to the pump is a suction-pipe when the plunger ascends, and a forcing-pipe when the plunger descends. The plunger, in ascending, draws the water out of the hot-well through the lowest of the valves, and, in descending, forces it through the centre valve into the space above, which communicates with the feed-pipe. Should the feed-cock be shut, so as to prevent any feed-water from passing through it, the water will raise the topmost valve, which is loaded to a pressure considerably above the pressure of the steam, and escape into the hot-well. This arrangement is neater and less expensive than that of having a separate loaded valve on the feed-pipe, with an overflow through

Fig. 318.



FEED-CHEST.

the ship's side, as is the more usual practice. *Figs.* 319. and 320. represent a double-acting deck feed-pump of a very complete and efficient construction.

Fig. 319.

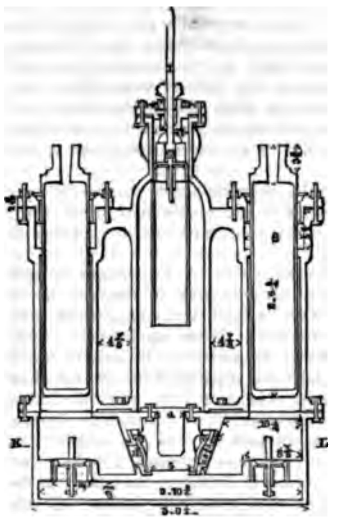
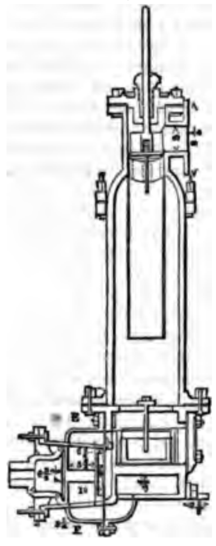


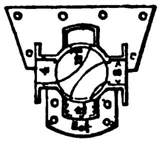
Fig. 320.



DECK PUMP OF DON JUAN.

It is of the plunger kind, which is preferable to that which operates by a piston. The air-vessel is furnished with an escape-valve, to prevent the pump from being split should it be put in connection with the engine when the cocks in the pipe leading to the boiler are closed, an accident which not unfrequently happens. *Fig.* 321. represents a four-way cock, the application of which enables the pump to draw from the sea, from the boiler, or from the bilge, and the pump can deliver either into the boiler or upon deck. This pump can be worked either by the engine or by hand: it is employed to feed the boilers when the engines are stationary, or to pump the boilers out, after they are blown off as far as can be accomplished by the steam. At other times it is useful for raising the water to wash the decks, to act as a fire-engine in case of fire, and to pump out the ship if she springs a leak.

Fig. 321.



In most of the new vessels fitted with tubular boilers, small engines have been introduced, to pump water into the boiler when the vessel stops under steam. Most of these engines are furnished with a crank and fly-wheel, but that introduced by Messrs. Penn, and of which we have given a representation in one of our plates, has no fly-wheel, and is a very compact and elegant arrangement. The pump-piston and the steam-piston are at different ends of the same rod, and, instead of the ordinary pump-valves, a slide-valve is introduced, which is situated at the opposite end of the steam-slide rod. The slide-valves are pipe-valves, and are moved by means of a tappet on the piston-rod. On another part of the same plate some views are given of a self-acting feed apparatus, which consists of a small chest, placed upon the front of the boiler at the level of the water-line, with ports, closed by a sliding plate, communicating with the water in the boiler and the steam above it. When these ports are opened the water rises to the same height in the chest as in the boiler, and the ports are opened and shut by the small engine at every stroke of the pump. While the pump is making its stroke the ports leading from the chest to the boiler are closed, and if the chest be chiefly filled with steam, it will be compressed by the entering water, and the chest will receive a charge of water, which, on the ports being opened, will flow into the boiler. But if there be but little steam in the chest when the pump is making its stroke, or the chest be filled with water from the rise of the water-level, the water discharged by the pump cannot gain admission, and it must therefore escape overboard through the loaded valve. Thus, as the water-level rises, the chest takes less water from the pump, and it takes more when the level falls, the effect of which in practice is to maintain a uniform water level in the boiler, however great the variations in the demand for steam. In some steam vessels floats have been introduced to regulate the feed, but their action cannot be depended on in agitated water, if applied after the common fashion. Floats would probably answer if placed in a cylinder which communicated with the water in the boiler by means of small holes; and a disc of metal might be attached to the end of a rod extending beneath the water-level, so as to resist irregular movements from the motion of the ship, which would otherwise prevent the satisfactory action of the apparatus.

This disc would be placed within the cylinder, and a short distance above it a fixed diaphragm might extend across the cylinder, between which and the moveable disc or piston on the rod the water would be compressed, in the event of any sudden disposition of the float to rise, such as might be created by the sudden motions of the ship; whereas by the slow and gradual subsidence of the water level from evaporation, the water in the cylinder would be able to subside, by gradually passing through the small holes in the cylinder and disc. One objection to this plan is, that the small holes would be liable to be closed up by deposit; and the preferable arrangement, probably, would be to place the float within the boiler, guided, but without any cylinder, and to apply a small oil cylinder, such as is used for the cataract of some pumping engines, to the end of the float rod where it protrudes through the top of the boiler. Such an arrangement would enable the float to resist suddenly acting forces, while any force that was gradual and steadily operative would still produce its due effect.

The admission of the feed-water into the boiler is sometimes regulated by cocks, and sometimes by spindle valves, raised and lowered by a screw. Cocks appear to us to be the preferable expedient, as they are less liable to accident or derangement than screw valves, and in modern steam vessels they are generally employed. The feed water is usually conducted from the feed cock to a point near the bottom of the boiler, by means of an internal pipe,—the object of the arrangement being to prevent the rising steam from being condensed by the entering water. By being introduced near the bottom of the boiler, it comes into contact in the first place with the bottoms of the furnaces and flues, and extracts heat from them, which could not be extracted by water of a higher temperature, whereby a saving of fuel is accomplished. In some cases the feed water is introduced into a casing around the chimney, from whence it descends into the boiler. This plan appears to be an expedient one when the boiler is short of heating surface, and more than a usual quantity of heat ascends the chimney; but in well-proportioned boilers a water casing round the chimney is superfluous. When a water casing is used, the boiler is usually fed by a head of water, the feed water being forced up into a small tank, from whence it descends into the boiler by the force of gravity, while the surplus runs to waste, as in the feeding apparatus of land engines, represented in *Fig.* 230.

Blow-off cocks are generally placed some distance from the boiler, but in our judgment they should always be placed quite close to it, as there are no means of shutting off the water from the pipe between the blow-off cock and the boiler, should fracture or leakage there arise. Every boiler must be furnished with a blow-off cock of its own, independently of the main blow-off cock on the ship's sides, so that the boilers may be blown off separately, and may be shut off from one another. The preferable arrangement appears to be, to cast upon each blow-off cock a bend for attaching the cock to the bottom of the boiler, and the plug should stand about an inch in advance of the front of the boiler, so that it may be removed or reground with facility. The floor-plate covering the blow-off cock should have a cooming, a few inches high, cast round a hole of sufficient diameter to admit a box key to turn the plug, and to each plug a box key should be fitted with a collar, at the level of the top of the cooming, of sufficient diameter to cover the hole and thickness of metal around it, and with the top of the key spindle supported by an eye attached to the boiler. These box keys would not be shifted from one plug to another, as at present, but each would remain in its place, and the engineer would only have to turn them when he wanted to blow off the boilers. The present method of using the blow-off cocks is very inconvenient. A small plate has to be removed to enable the box key to be applied; coal sometimes is lying upon the plate, which has to be removed, and coal-dust gets into the bilge in these continual removals, which chokes the roses of the bilge pumps. In dark nights and rough weather, the engineer requires to feel the nick in the top of the plug, which is often filled with coal-dust and grease, before he can assure himself whether the cock is open or shut, and the operation of turning the cocks is more difficult when the spindle of the key is without support. These evils may be remedied by the arrangement suggested. The spindle will require to be made with a hole or eye to admit a handle wherewith to turn it round, and it would be an easy thing to make the stud supporting the top of the spindle of such a form that the handle for turning the spindle could not be withdrawn when the cock was open. The cock, therefore, could not be left open without the handle being left in its place, where it would stand out from the boiler, incommode the firemen, and duly notify the neglect.

The general arrangement of the blow-off pipes is to put a main blow-off pipe beneath the floor-plates across the ship at the end of the engines, and into this pipe to lead a separate pipe, furnished with a cock, from each boiler. The main blow-off cock, where it penetrates the ship's side, is furnished with a cock; and in modern steam vessels Kingston's valves are also used, which consist of a spindle or plate valve fitted to the exterior of the ship, so that if the internal pipe or cock breaks, the external valve will still be operative. Some expedient of this kind is almost necessary, as the blow-off cocks require occasional re-grinding, and the sea cocks cannot be re-ground without putting the vessel into dock, except by the use of Mr. Kingston's valves or some equivalent expedient. When old vessels are getting new sea cocks applied, it may answer to make the old cocks serve the purpose of Kingston's valves, the new cocks being applied between the old cocks and the blow-off pipes.

All the cocks about an engine should be provided with bottoms and stuffing-boxes, and reliance should never be placed upon a single bolt passing through a bottom washer for keeping the plug in, in the case of any cock communicating with the boiler, for a great pressure is thrown upon that bolt if the pressure of the steam be high and the plug be made with much taper; and should the bolt break or the threads strip, the plug will fly out, and persons standing near may be scalded to death,— an accident which has sometimes happened. In large cocks it appears the preferable plan to cast the bottoms in; and the metal of which all the cocks about a marine engine are made should be of the same quality as that used in the composition of the brasses, and should be without lead or other deteriorating material. In some cases the bottoms of cocks are burnt in with hard solder, but this method cannot be depended upon, as the solder is softened and wasted away by the hot salt water, and in time the bottom leaks or is forced out. The stuffing-boxes of cocks should be made of adequate depth, and the gland should be secured by means of four strong copper bolts. The taper of blow-off cocks is an important element in their construction; as if the taper be too great, the plugs will have a continual tendency to rise, which, if the packing be slack, will enable grit to get between the faces, while, if the taper be too little, the plug will be liable to jam, and a few times grinding will sink it so far through the shell, that the water-ways will no longer correspond. One-eighth of an inch deviation from the perpendicular for every inch in height is a common angle for the side of the cock, which corresponds with one quarter of an inch difference of diameter in an inch of height; but we think a somewhat greater taper than this, or one-third of an inch difference of diameter for every inch of height, is a preferable proportion. The bottom of the plug must be always kept a small distance above the bottom of the shell, and an adequate surface must be left above and below the water-way, to prevent leakage. Cocks formed according to these directions will be found to operate satisfactorily in practice.

Gauge cocks are generally very inartificially made, and occasion needless trouble to the engineer. They are rarely made with stuffing-boxes, and are for the most part adorned with stalactites of salt after a short period of service, in consequence of leakage. The water discharged from them, too, disfigures the front of the boiler, and adds to the corrosion in the ash-pits. It would be preferable to combine the gauge cocks appertaining to each boiler into a single upright tube, connected suitably with the boiler, and the water flowing from them could be directed downwards into a funnel tube communicating with the bilge. The gauge cocks and also the glass-tube cocks should be furnished with stuffing-boxes, and with bottoms, unless the water enters through the bottom of the plug. The glass gauge tubes should always be fitted with a cock at each neck, communicating with the boiler, so that both the water and steam may be shut off if the tube breaks. The gauge cocks frequently have pipes running up within the boiler, to the end that a high-water level may be made consistent with an easily accessible position of the gauge cocks themselves. With the glass tubes, however, this species of arrangement is not possible, and the glass tubes must always be placed in the position of the water level, whether it be high or low.

The sea injection cocks are usually made in the same fashion as the sea blow-off cocks, and of about the same size. The injection water is generally admitted to the condenser by means of a slide valve, but a cock appears to be preferable, as it is more easily opened, and has not any disposition to shut of its own accord. The sea injection pipes should be put through the ship's side in advance of the paddles, so that the water drawn in may not be injuriously charged with air. In some cases the suction pipe of the deck pump leads into the injection pipe; but it is preferable to put a pipe through the ship's side for the exclusive use of the deck pump, as is the general practice. The waste water pipe, passing from the hot well through the vessel's side, is provided with a stop valve, called the discharge valve, which is usually made of the spindle kind, so as to open when the water coming from the air pump presses against it. In some cases this valve is a sluice valve, but the hot well is then almost sure to be split if the engine be set on without the valve having been opened. The opening of the waste water pipe should always be above the load water line, as it will otherwise be difficult to prevent leakage through the engine into the ship, when the vessel is lying in harbour.

Boilers are now generally supplied with stop-valves, whereby one boiler may be thrown out of use without impairing the efficacy of the remainder. These stop valves are usually spindle valves of large size, and they are for the most part set in a pipe which runs across the steam chests connecting the several boilers together. The spindles of these valves should project through stuffing-boxes in the covers of the valve chests, and they should be balanced by a weighted lever and kept in continual action by the steam. If the valves be lifted up and be suffered to remain up, as is the usual practice, they will become fixed by corrosion in that position, and it will be impossible after some time to shut them on any emergency. These valves should always be easily accessible from the engine room, and it ought not to be necessary for the coal boxes to be empty to gain access to them. The safety valves should not be set on the common pipe connecting the boilers, but each boiler should have a safety valve of its own set direct upon the steam chest, for if the stop valve should jam, and the safety valve be exterior to it, the safety valve cannot contribute anything to save the boiler from explosion. Each boiler also should have a distinct steam-gauge and a distinct atmospheric valve, if atmospheric valves be applied at all, but they scarcely appear to be necessary in the case of tubular boilers, which are capable of withstanding the atmospheric pressure with impunity.

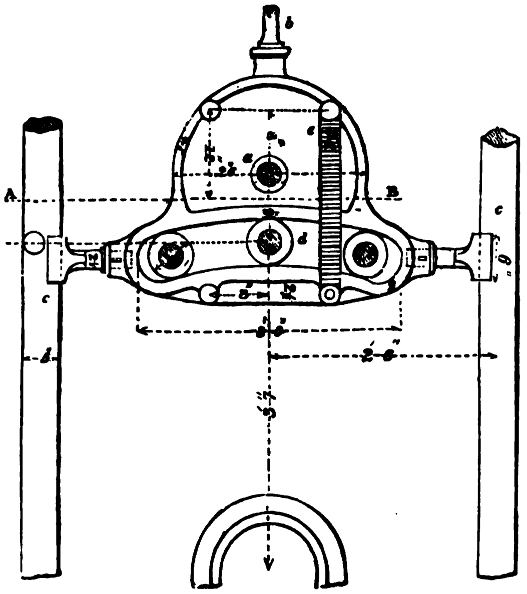
The pipes of marine engines should always be made of copper. Cast-iron blow-off pipes have in some cases been employed, but they are liable to fracture, and are dangerous. Every pipe passing through the ship's sides, and every pipe fixed at both ends and liable to be heated and cooled, should be furnished with a faucett or expansion joint, and in the case of cast-iron pipes, the part of the pipe fitting into the faucett should be turned. In the distribution of the faucetts of the pipes exposed to pressure, care must be taken that they be so placed that the parts of the pipe cannot be forced asunder by the strain, as serious accidents have occurred from the neglect of this precaution. A faucett is usually placed where the main steam-pipe joins the branch steam-pipes proceeding to the cylinders, and if those branch steam-pipes are attached to the cylinders or valve casings by means of faucetts, the whole of the branch steam-pipes may swivel round on these faucetts and leave the main steam-pipe, which will then discharge its full volume of steam into the engine room, an accident which could hardly fail to be attended with the most disastrous consequences.

Where the pipes pierce the ship's side, they should be made tight as follows:—The hole being cut, a short piece of lead pipe with a broad flange at one end should be fitted into it, the place having been previously smeared with white lead, and the pipe should then be beaten on the inside until it comes into close contact all round with the wood. A loose flange should then be slipped over the projecting end of the lead pipe, to which it should be soldered, and the flanges should both be nailed to the timber with scupper nails, white lead having been previously spread underneath. This method of procedure, it is clear, prevents the possibility of leakage down through the timbers, and all therefore that has to be guarded against after this precaution, is to prevent leakage into the ship. To accomplish this object, let the pipe which it is desired to attach be put through the leaden hawse, and let the space between the pipe and the lead be packed with gasket and white lead. The pipe must have a flange upon it to close the hole in the ship's side; the packing must then be driven in from the outside and be kept down by means of a gland secured with bolts passing through the ship's side. If the pipe is below the water line, the gland must be of brass, but for the waste water pipe a cast-iron gland will answer. This method of securing pipes penetrating the side, however, though the best for wooden vessels, will, it is clear, fail to apply to iron ones. In the case of iron vessels, it appears to be the best practice to attach a short iron nozzle, projecting inwards, to the skin, for the attachment of every pipe below the water line, as the copper or brass would waste the iron of the skin if the attachment were made in the usual way.

Parts of oscillating Engines.—The most important parts of oscillating engines are the piston, the piston-rod stuffing-box, the trunnions, and the attachment for the valve. The two former parts we have already described; we shall here give the chief details of the two latter.

Fig. 322. represents the valve attachment of H. M. steam vessel the Trident, constructed by Messrs. Boulton and Watt, cylinder 70¾ in. diameter, and 5 ft. stroke, and reckoned at 350 horse power. The eccentric rod is attached to the stud *a*, which is fixed to the centre of a plate forming part of a frame which is guided vertically by means of the guide-

Fig. 322.

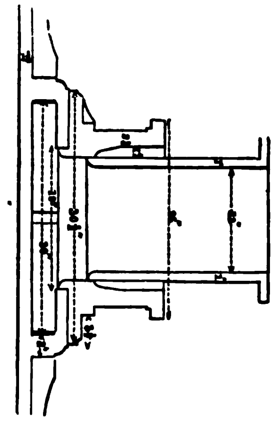


VALVE GEAR OF OSCILLATING ENGINE, BY MESSRS. BOULTON AND WATT.
Scale half an inch = 1 Foot.

rod *b*, and by the columns of the engine at *c c*. *d* is the end of the valve lever which is moved up and down by the frame, whatever position in the arc the end of the lever may occupy in consequence of the oscillation of the cylinder. *e* is a rack whereby the frame may be moved up or down by means of a shaft at AB, when the eccentric rod is not in gear, and at the end of the shaft a wheel is situated for starting the engine. The curved groove in which the end of the valve lever moves is part of a circle, but it is not swept from the centre of the trunnion when the valve is at half stroke, but with a radius equal to the distance of the centre of the valve shaft from the centre of the trunnion, when the cylinder is perpendicular. Messrs. Penn do not form the curve in this way, but sweep it from the centre of the trunnion when the valve is at half stroke; and although the same motion of the valve is not thus obtained as when there is no oscillation, the difference is very slight, and is moreover considered to be a better motion than if no disturbance had taken place. It appears to us that the use of a curve might be dispensed with altogether by observing a suitable adjustment of the eccentric; the effect would probably be to increase slightly the side pressure on the piston-rod, but the increase would be altogether inappreciable in the case of equilibrated valves which may be wrought with an inconsiderable exercise of force.

Fig. 323. represents one of the trunnions of the Trident, which instead of being cast upon the cylinder, as is the usual practice, are bolted on with twelve $1\frac{1}{4}$ in. bolts, and are strengthened by twelve brackets, 1 inch thick, cast on the flanges of attachment. There is a projecting ring, it will be observed, left upon the part which is to be bolted on, which is accurately fitted into the hole in the belt in order to obviate slackness sideways. A rib $1\frac{1}{2}$ in. thick runs back from the hole on each side in the middle of the belt, to tie the belt more effectually to the cylinder, and above and below the belt a feather runs vertically $1\frac{1}{2}$ in. thick, and tapering in depth from the belt till it runs off to nothing on the cylinder side.

Fig. 323.



TRUNNION OF OSCILLATING ENGINE, BY MESSRS. BOULTON AND WATT.
Scale half an Inch = 1 Foot.

The bearing part of the trunnion is 22 in. diameter, 7 in. long, and the metal is $2\frac{1}{4}$ in. thick; the steam pipe entering the trunnion 1 in. thick, and the packing space between the pipe and trunnion $1\frac{1}{4}$ in. wide. The gland for compressing the packing is usually put on in two pieces. The pipe requires to be so made that it can be pushed in against the cylinder in order to accommodate its outer attachment. It is not necessary to make provision at the outer end of the trunnion-pipe for the falling of the trunnion by wear, as the wear is so small as to be of no practical moment. The thickness of metal of the cylinder is $1\frac{1}{4}$ in.; the thickness of the top and bottom of the belt is $2\frac{1}{4}$ in. in the wake of the trunnion, and 2 in. in other places. The diameter of the hole in the belt is 18 in.; the internal diameter of the steam pipe is 13 in.; and the diameter over the flange for the attachment of the trunnion is $30\frac{1}{4}$ in. The interior of the belt in the wake of the trunnion measures 29 in. deep and $4\frac{1}{2}$ in. wide. The crank shaft bearings are 12 in. diameter and 13 in. long. The paddle wheels are overhung, and the outer journal of the shaft is 14 in. diameter, and 14 in. long; the part on which the centre is fixed, from whence the arms diverge, being 16 in. diameter, and 24 in. long. When the paddle is overhung, the shaft increases in size at the outer end, instead of diminishing as in other cases. The diameter of the wheels is 22 ft.; the floats are 2 ft. broad and 9 ft. long, and have a dip of 4 ft. 7 in. from the load water line, at which point the vessel draws 11 ft. of water. The crank pin is 9 in. in diameter, and has a length of bearing for the connecting rod of 14 in. The diameter of the Trident's piston-rod is $7\frac{1}{2}$ in.; we think the introduction of larger piston-rods than have yet been introduced in oscillating engines would be an improvement, and would add to the durability of the engines. Each cylinder measures 8 ft. 1 in. across from centre to centre of trunnion, and 11 ft. 6 in. from the level of the trunnion to the level of the shaft.

The position of the trunnion should be a little above the centre of gravity of the cylinder, so that it will have no tendency to tilt over when the piston-rod is disengaged from the crank-pin, and very little tendency at the same time when pushed over to resume the perpendicular. The plan of attaching a weight to one side of the cylinder to balance the valve casing is now discontinued in the best engines, and two valves are employed which balance one another. These valves are placed one on each side of the trunnion, so that they may both be wrought by the same eccentric. If the curved eccentric frame were discarded, the eccentric rod might be attached immediately to a cross-head, from the ends of which the two valve rods descended, and the intermediate gear at present used might thus be dispensed with.

Engines applied direct to the Screw. — It requires but little penetration to foresee that the present species of marine engine must be given up if the screw propeller gains a general introduction, as it appears destined to do; for the engines will in that case be coupled immediately to the screw shaft, which, as it requires to revolve much more quickly than a paddle-shaft, involves a greatly increased speed of piston. Small engines, with the pistons moving at a quick speed, will exert the same power as large engines moving with a slow speed; and small engines, by being applied to the screw shaft direct, may be made to do the work of large ones. This is a manifest advantage to steam navigation, as a vessel may be constructed with very large power without being inconveniently burdened with the weight of the engines; and it is also an advantage to the makers of engines, who will thus be enabled to produce a given power at a less cost. The only impediment to the general introduction of this system lies in the difficulty of driving the air-pump at a high speed without causing the valves to strike so hard as to wear themselves out very quickly. The difficulty may, however, it appears to us, be met by making the air-pump piston without valves, and opening and shutting the foot valve passage by means of a slide valve, the motion for working which is derived from the eccentric rod. The delivery valve must still be opened by the pressure of water in the pump; but it may be made to consist of a piston valve with skewed ports, such as is represented in *fig.* 233., and it may be closed, or the piston be brought opposite to the ports by means of a pendulum weight at the end of a lever moving outside. Most of the engines at present in course of construction for direct application to the screw, are made with four cylinders lying horizontally with two cranks upon the screw shaft, to which the connecting rods are attached, the connecting rods being joined to the top of the piston rods, as in the Gorgon, or locomotive construction. Oscillating engines, laid at an angle of 45°, and joined to a single crank on the shaft, have in some cases been employed; and we think this arrangement is upon the whole the preferable one. The air-pump may be made double-acting, and may be worked from the same crank-pin to which the piston-rods are attached; the pin, however, being made eccentric in the part to which the air-pump rod is attached, in order to give the pump a shorter stroke than the piston. The crank and crank-pin will, if this arrangement be adopted, be stronger if made in the same piece, and the neck of the shaft from which the crank overhangs must be made stronger than usual. If the air-pump be made double-acting, as appears to be the preferable practice, its diameter may be very small, but the foot and delivery valve passages must be larger than usual in proportion to the size of the pump. If a piston valve be adopted for the delivery valve, it will be expedient to balance the valve by means of a counterweight, as is done in case of the steam valve, adding then a pendulum, or a short crank pulled into the vertical position by a rod loaded with a weight, the end of the rod being suitably guided by a swivelling eye, in order to bring back the valve, or retain the piston opposite the ports until the pressure comes on. It is clear that, if this arrangement be adopted, the thrust of the shaft forwards, which in the case of the Rattler screw steamer is equivalent to a weight of four tons, cannot be sustained by the end of the shaft; and the best arrangement appears to be, to receive the thrust upon a collar on the shaft, which works within an oil cylinder, — oil being forced continually by a small pump worked by the engine between the end of the oil cylinder and the collar, until the collar is forced back with a pressure equal to that of the forward thrust. It is not expedient, however, to trust to the oil alone; and, therefore, between the collar and the bottom of the oil cylinder, and also between the collar and the top of the oil cylinder — so as to give security for backing — rollers carried by rings, as in the case of the rollers of a swivel bridge, or railway turn-table, should be interposed. These rollers should be as numerous as can be conveniently applied; they should each touch only in one point; should be made narrow, and several of these narrow rollers should be set upon the same spindle, so as to increase the quantity of the bearing surface. The collar and ends of the oil cylinder should consist of plates of hardened steel, and the rollers should also be of hardened steel, and be all made of exactly the same diameter. The oil cylinder would have to be supplied with a safety valve on each side of the collar, so that any surplus oil sent in by the pump would be able to escape into a small tank, out of which the pump would draw. By these expedients, it appears clear to us that the thrust of the screw may be effectually and satisfactorily counteracted. It appears expedient to tooth out the eye of the collar, and to make it of sufficient length to serve as a coupling box, the end of the shaft proceeding from the screw to the collar being similarly toothed, and fixed fast into the collar; while the end of the shaft proceeding from the collar to the engine is toothed in the same fashion, but so fitted as to slide endways in the collar. By this arrangement, should the oil cylinder yield slightly, or the rollers wear, the engine framing will still be preserved from the forward strain; the only effect of such accidents being to make the engine shaft slip somewhat further into the collar. The edge of the collar would be furnished with cupped leathers upon each side, of the same description as those used for the rams of hydraulic presses. The improvement of the species of engine that is adapted for direct application to the screw, is one of the most important objects that can engage the attention of the marine engineer; for the ultimate universality of screw propulsion appears to be the most probable conjecture at the present time; and if the screw supersedes the paddle, the best form of direct action engine applicable to the screw, will secure the most extended patronage. Unless a very perfect rotatory be devised, the oscillating engine, coupled direct to the crank in the manner we have described, will probably maintain the supremacy, and we would commend that form to those who are desirous of making a selection that is not likely speedily to involve much further change.

How to erect Side Lever Engines. — Level the bed-plate lengthways and across, and strike a line up the centre as near as possible in the middle, which indent with a chisel in various places, so that it may at any time be easily found again. Strike another line at right angles with this, either at the cylinder or crank-centre, by raising a perpendicular in the usual manner. Lay the other sole-plate alongside at the right distance, and strike a line at the cylinder or crank centre of it also, shifting either sole-plate a little endways, until these two transverse lines come into the same line, which may be ascertained by applying a straight edge across the two sole-plates. Strike the rest of the centres across, and drive a pin into each corner of each sole-plate, which file down level, so as to serve for points of reference at any future stage. Next try the cylinder, or plumb it on the inside roughly, and see how it is for height, in order to ascertain whether much will be required to be chipped off the bottom, or whether more requires to be chipped off the one side than the other. Chip the cylinder bottom fair; set it in its place, plumb the cylinder very carefully with a straight edge and silk thread, and scribe it so as to bring the cylinder mouth to the right height, then chip the sole-plate to suit that height. The cylinder must then be tried on again, and the parts filed wherever they bear hard, until the whole surface is well fitted. Next chip the place for the framing; set up the framing, and scribe the horizontal part of jaw with the scriber used for bottom of cylinder, the upright part being set to suit the shaft centres, and the angular flange of cylinder where the stay is attached having been previously chipped plumb and level. The stake-wedges with which the framing is set up preparatory to the operation of scribing, must be so set as to support equally the superincumbent weight, else the framing will spring from resting unequally, and it will be altogether impossible to fit it well. In some of the modern direct-action engines, many of the directions here given will be found needless, for the cylinder-flange and cylinder-bottom are both faced in the boring mill, and the framing consists of malleable iron rods, which involve but little difficulty in fitting them together; but whoever can fit together a side lever engine with cast-iron framing will find little difficulty in fitting together any other kind.

Centres and Lengths of Rods. — In fixing the positions of the centres, it appears to be the most convenient way to begin with the main centre. The height of the centre of the cross-head at half-stroke above the plane of the main centre, is fixed by the drawing of the engine, which gives the distance from the centre of cross-head centre at half-stroke, to the flange of the cylinder; and from thence it is easy to find the perpendicular distance from the cylinder-flange to the plane of the main centre. merely by putting a straight edge along level, from the position of the main centre to the cylinder, and measuring from the cylinder-flange down to it, raising or lowering the straight edge until it rests at the proper measurement. The main centre is in that plane, and the fore and aft position is to be found by plumbing up from the centre line on the sole-plate. To find the paddle-shaft centre, plumb up from the centre line marked on the edge of the sole-plate, and on this line lay off from the plane of the main centre the length of the connecting rod, if that length be already fixed; or otherwise the height fixed in the drawing of the paddle-shaft above the main centre. To fix the centre for the parallel-motion shaft, when the parallel-bars are connected with the cross-head; lay off on the plane of main centre the length of the parallel bar from the centre of the cylinder, deduct the length of the radius crank, and plumb up for the central line of motion shaft; lay off on this line measuring from the plane of main centre, the length of the side-rod; this gives the centre of parallel motion-shaft, when the radius-bars join the cross-head, as is the preferable practice where parallel motions are used. The length of the connecting-rod is the distance from the centre of the beam when level, or the plane of the main-centre, to the centre of the paddle-shaft. The length of the side-rods is the distance from the centre-line of the beam when level, to the centre of the cross-head when the piston is at half-stroke. The length of the radius-rods of the parallel motion is the distance from the point of attachment on the cross-head or side-rod, when the piston is at half-stroke, to the extremity of the radius-crank, when the crank is horizontal; or, in engines with the parallel motion attached to the cross-head, it is the distance from the centre of the pin of the radius-crank, when horizontal to the centre of the cylinder.

How to set the Parallel Motion. — We have already described at page 210. the method of setting the parallel motion of a beam land engine. In marine engines, having fixed the centre of the parallel motion shaft in the manner just described, it only remains to put the parts together when the motion is attached to the cross head; but when the motion is attached to the side rod, the end of the parallel bar must not move in a perpendicular line, but in an arc, the versed sine of which bears the same ratio to that of the side lever that the distance from the top of the side rod to the point of attachment bears to the total length of the side rod.

The parallel motion when put in its place should be tested by raising and lowering the piston by means of the crane: first set the beams level, and shift in or out the motion-shaft, plummer-blocks, or bearings, until the piston-rod is upright. Then move the piston to the two extremes of its motion: if at both ends the cross-head is thrown too much out, the stud in the beam to which the motion side-rod is attached is too far out, and must be shifted nearer to the main centre: if at the extremities the cross-head is thrown too far in, the stud in the beam is not out far enough. If the cross-head be thrown in at the one end and out equally at the other, the fault is in the motion side-rod, which must be lengthened or shortened to remedy the defect. We have already given, in page 100., rules for the computation of the proper lengths of all kinds of parallel motions, and by these rules the workman may ascertain whether the rods furnished to him to be fitted together are properly proportioned.

How to set the Slide-Valves. — The first thing is to ascertain whether the eccentric-rod is of the right length. To determine this, put the valve in the middle of its stroke, so that both ports are covered equally, and fix it in that position. Next, turn round the eccentric on the shaft until the eccentric-rod has reached the furthest point of its travel *from* the shaft, and square up from the side of the eccentric pin a line upon the rod. Turn round the eccentric again until the eccentric rod reaches the end of its travel *towards* the shaft, and square up another line on the rod *from the other side* of the pin. If the eccentric notch be equally distant from the lines thus marked upon the eccentric-rod, the rod is of the right length; but if the notch be too far down upon it, the rod requires to be shortened; and if too far up, to be lengthened — in each case to an extent equal to the deviation of the notch from the central line. Thus, if on trial, the notch be found to be half an inch nearer to the lower than to the upper line, the notch will require to be shifted up a quarter of an inch, to place it midway between the lines; and to do this, the rod must be *shortened* a quarter of an inch; whereas, if the notch be half an inch nearer the upper than the under line, the rod will require to be *lengthened* a quarter of an inch, and so on in all other proportions.

The right length for the eccentric-rod having been thus obtained, and the rod having been adjusted thereto, the next step is to set the crank perpendicular. In a workshop this is easily done by a plumb-line, but in a steam-vessel recourse must be had to another method. Find on the sole-plate, or cylinder-mouth if a direct action engine, the transverse centre line answering to the centre of the shaft. Describe on the large eye of the crank a circle of the size of the crank-pin, and lay off in a fore and aft direction from the transverse centre-line on cylinder-mouth or sole-plate, a distance equal to the radius or half diameter of the crank-pin. Stretch a line from the point thus marked off to the edge of the circle described on the large eye of the crank, and turn round the paddle-wheels until the crank-pin just touches the stretched line — the crank will then be perpendicular, and may be set by this method either on top or bottom centre.

The crank having been set in a perpendicular position while the valve is set and fixed with the amount of lead it is intended to give, the eccentric has only to be turned round upon the shaft until the notch comes opposite to the pin and the rod falls into gear, to determine the right position of the eccentric on the shaft. The situation of the eccentric may then be marked upon the shaft, and the catches fitted on in the usual way. The valve may first be set for going a-head, and may then be set for going astern, — shifting round the eccentric to the opposite side of the shaft until the rod again falls into gear. The position answerable to going a-head in some engines will be that answerable to going astern in others, depending on the way in which the engines are placed, the arrangement of the levers, and the kind of valve employed. It is necessary to recollect that it is the catches which drive the eccentric, and not the eccentric the catches, mistakes having sometimes arisen from forgetfulness of this condition

It is impossible to give any general rule for finding the length of the valve levers or the throw of the valve. In most engines, however, the travel of the valve is twice the depth of the port, and the throw of the eccentric is equal to the travel of the valve, so that motion is neither gained nor lost by the levers. In engines which do not operate expansively, the depth of the valve face is equal to the depth of the port; but all modern engines have a certain amount of lap or cover on the steam side; and some on the eduction side also. In the Thames and Medway steamers by Messrs. Maudslay, the travel of the valve is 16 in., and the length of valve lever 8¾ in.; depth of port, 6 in.; length of port, 26 in.; distance from upper edge of upper port to under edge of under port, 8 ft. 9¾ in.; and distance between extreme edges of valve faces, 8 ft. 9½ in.; so that instead of there being cover upon the eduction side, the valve is one eighth of an inch short at each end, and will not cover the ports in any position. In some engines the upper face is made narrower than the under face. In Messrs. Maudslay's 50 horse power engines, the breadth of the port is 3 in., and its length 15 in.; the breadth of the lower valve face is 5 in., and of the upper one, 4⅝ in. In the 48 inch cylinders of the same makers, the size of port is 3¼ in. by 18 in.; in the 54 in. cylinders the size of port is 20 in. by 4 in.; the valve faces, 8 in., and 7¼ in. broad; and the length of the travel, 11 in. Other makers adopt different modes of setting the valves — we believe with little difference in the efficiency of the engine. We must refer the reader to the investigations and rules we have already given respecting slide-valves, as the best guide we can furnish for fixing the lap, lead and other elements, in the absence of a uniformity of practice.

How to put the Engines into a Steam Ship. — First, measure across from the inside of paddle-bearers to the centre of the ship, to make sure that the central line, running in a fore and aft direction on the deck or beams, usually drawn by the carpenter, is really in the centre; and if it is not, make a fore and aft line or mark that is in the centre. Stretch a line across between the paddle-bearers in the direction of the shaft: to this line in the centre of the ship where the fore and aft mark has been made, apply a square with arms six or eight feet long, and bring a line, stretched perpendicularly from the deck to the keelson, accurately to the edge of the square; the lower point of the line where it touches the keelson will then be immediately beneath the mark made on the deck. If this point does not come in the centre of the keelson, it will be better to shift it a little, so as to bring it to the centre, altering the mark on the deck correspondingly, provided either paddle shaft will admit of this being done — one of the paddle-brackets being packed behind with wood, to give it an additional projection from the side of the paddle-bearer. Continue the line fore and aft upon the keelson as nearly as can be judged in the centre of the ship; stretch another line fore and aft through the mark upon the deck, and look it out of winding with the line upon the keelson. Fix upon any two points equally distant from the centre, in the line stretched transversely in the direction of the shaft; and from those points as centres, and with any convenient radius, sweep across the fore and aft line to see that the two are at right angles; and if not, shift the transverse line a little to make them so. From the transverse line next let fall a line upon each outside keelson, bringing the edge of the square to the line, the other edge resting on the keelson. A point will thus be got on each outside keelson perpendicularly beneath the transverse line running in the direction of the shaft, and a line drawn between those two points will be directly below the shaft. To this line the line of the shaft marked on the sole-plate has to be brought, care being taken at the same time, that the right distance is preserved between the fore and aft line upon the sole-plate, and the fore and aft line on the central keelson. Before any part of the machinery is put in, the keelsons should be dubbed fair and straight, and be looked out of winding by means of two straight edges. The art of placing engines in a ship is more a piece of plain common sense than any other feat in engineering; and every man of intelligence may easily settle a method of procedure for himself. Plumb-lines and spirit levels, it is obvious, cannot be employed on board a vessel; and the problem consists in so placing the sole-plates, without these aids, that the paddle-shaft will not stand awry across the vessel, nor be carried forward beyond its place by the framing shouldering up more than was expected. As a plumb-line cannot be used, recourse must be had to a square; and it will signify nothing at what angle with the deck the keelsons run, so long as the line of the shaft across the keelsons is squared down from the shaft centre. The sole-plates being fixed, there is no difficulty in setting the other parts of the engine in their proper places upon them. The paddle-wheels must be hung from the top of the paddle-box, to enable the shaft to be rove through them; and the cross stays between the engines should be fixed in when the vessel is afloat. To try whether the shafts are in a line, turn the paddle-wheels, and try if the distance between the cranks is the same at the upper and under, and the two horizontal centres; if not, move the end of the paddle-shaft up or down, or backwards or forwards, until the distance between the cranks at all the four centres is the same.

Miscellaneous Remarks respecting Marine Engines. — The cylinders should be felted, and then cased with wood that has been baked until it will shrink no longer. The steam-pipes should be cased in the same way, and the boilers should be felted, and then covered with sheet lead, soldered at every joint. The whole of the screws about the engine should be made according to a uniform system of threads, and the nuts of the same sized bolts should also be of the same size, so that a single spanner will serve for those nuts. The spanners intended for polished nuts should be close and single-ended, and they should be themselves polished and case-hardened, and ranged in regular order on one of the engine-room bulkheads. A pair of brass-sheaved blocks for raising the cylinder cover, and another smaller pair for raising the air-pump cover, should be provided; and a strong screw, with a large eye at the end, for raising the paddle-wheel. Strong spanners should also be provided for the holding-down bolts, with eyes at the end, to which a tackle may be applied; and a box key for tightening down the bolts of the paddle-shaft plummer-blocks through the crank-hatch. Tallow kettles are little needed if the pistons and cylinder stuffing-boxes have metallic packings. Oil-cans and lamps should be ranged on a shelf in separate stands, so that they cannot fall off when the vessel rolls. For every article of engine-room furniture there should be a convenient and conspicuous place; and if there be any articles of spare gear, they should be all kept *in sight.* Unless this be done, they are almost sure to be eaten up with rust, as neglect generally follows their stowage in an unfrequented or inaccessible place.

In most steam-vessels a good deal of trouble is caused by the holding-down bolts, which are generally made of iron. Sometimes they go through the bottom of the ship, and at other times they merely go through the keelson, a recess being made in the floor or timbers to admit of the introduction of a nut. The iron, however, wears rapidly away in both cases, even though the bolts are tinned; and it has been found the preferable method to make such of the bolts as pass through the bottom, or enter the bilge, of Muntz's metal, or of copper. In side-lever engines four Muntz's metal bolts may be put through the bottom at the crank end of the framing of each engine, four more at the main centre, and four more at the cylinder, making twelve through bolts to each engine; and it is more convenient to make these bolts with a nut at each end, as in that case the bolts may be dropped down from the inside; and the necessity is obviated of putting the vessel on very high blocks in the dock, in order to give room to put the bolts up from the bottom. The remainder of the holding-down bolts may be of iron; and may, by means of a square nut, be screwed into the timber of the keelsons as wood screws, the upper part being furnished with a nut, which may be screwed down upon the sole-plate, so soon as the wood screw portion is in its place. If the cylinder be a fixed one, it should be bolted down to the sole plate by as many bolts as are employed to attach the cylinder-cover, and they should be of copper or brass, in any situation that is not easily accessible. In well-formed bolts the spiral groove penetrates about one-twelfth of the diameter of the cylinder, so that the diameter of the solid cylinder which remains is five-sixths of the diameter over the thread. The strain to which iron may be safely subjected in machinery, is one fifteenth of its utmost strength, or 4000 lbs. on the square inch, so that 2180 lbs. may be sustained by a screw an inch in diameter at the outside of the threads. The strength of the holding-down bolts, therefore, may easily be computed, when the elevating force of the piston or main centre is known, but it is expedient very much to exceed this strength in practice, on account of the elasticity of the keelsons, the liability to corrosion, and other reasons.

A very useful species of oil-cup is now employed in a number of steam-vessels; and which, it is said, accomplishes a considerable saving of oil, at the same time that it more effectually lubricates the bearings. A ratchet-wheel is fixed upon a little shaft which passes through the side of the oil-cup, and is put into slow revolution by a pendulum attached to it outside; and in revolving, it lifts up little buckets of oil and empties them down a funnel upon the centre of the bearing. Instead of buckets, a few short pieces of wire are sometimes hung on the internal revolving wheel, the drops of oil which adhere to them on rising from the liquid being deposited upon a high side set upon the funnel, and which in their revolution the hanging wires touch. By this plan, however, the oil is not well supplied at slow speeds, as the drops fall before the wires are in the proper position for feeding the journal. Another lubricator consists of a cock or plug inserted in the neck of the oil-cup, and set in revolution by a pendulum and ratchet-wheel, or any other means. There is a small cavity in one side of the plug, which is filled with oil when that side is uppermost, and delivers the oil through the bottom-pipe when it comes opposite to it. In some cases bearings heat from making a cruciform groove in the top brass for the distribution of the oil, the effect of which is to leave the top of the bearings dry. In the case of revolving journals the plan of cutting a cruciform channel for the distribution of the oil does not do much damage; but in other cases, as in beam-journals for instance, it is most injurious, and the brasses cannot wear well wherever the plan is pursued. The right way is to make a horizontal groove along the brass where it meets the upper surface of the bearing, so that the oil may be all deposited on the highest point of the journal, leaving the force of gravity to send it downwards. This channel should of course stop short a small distance from each flange of the brass, otherwise the oil would run out at the ends.

The paddle shaft, where it passes through the vessel's side, is usually surrounded with a lead stuffing-box, which will yield if the end of the shaft falls. This stuffing-box prevents leakage into the ship from the paddle-wheels, but it is expedient as a further precaution to have a small tank on the ship's side immediately beneath the stuffing-box, with a pipe leading down to the bilge to catch and conduct away any water that may enter. The bearing at the outer end of the paddle shaft is sometimes supplied with tallow forced into a hole in the plummer block cover, as in the case of water wheels, but for vessels intended to perform long voyages, it is preferable to have a pipe leading down to an oil cup above the journal, from the top of the paddle-box, through which pipe oil may at any time be supplied. The eccentrics should be fitted with pans beneath them to catch the oil which falls. In vessels fitted with Hall's condensers, the pistons and stuffing-boxes must be supplied with oil instead of tallow, as the tallow congeals in the pipes of the condensers and chokes them up. The bolts for holding on the paddle floats should be made extra strong on account of the corrosion to which they are subject, and the nuts should be made large and should be square, so that they may be effectually tightened up even though the corners are worn away by corrosion. Paddle floats, when consisting of more than one board, should be bolted together edgeways by means of bolts running across their whole breadth; they should not overhang the ring much at the outside of the wheel, else they will be very liable to be broken off when the wheel strikes the water heavily. The aftermost paddle beam should come as close as possible to the wheel to prevent the spray from being carried up. The angular pieces or wales running from the extremities of the paddle beams to the back of the deck houses, are best when fitted with iron gratings, as wooden gratings are liable from their greater opposing surface to be carried away. The brackets supporting the paddle-box steps should consist of circular pieces running round the paddle-box from step to step, as when put on with isolated brackets the steps are liable to be carried away by the sea. The funnel shrouds should consist of rope of the same dimensions as the shrouds of the main mast, but a few feet at the top should consist of chain, as rope close to the funnel would be burned.

It is very difficult to fix engines effectually which have once begun to work in the ship, for in time even the surface of the keelsons on which the engines bear becomes worn uneven, and the engines necessarily rock upon it. As a general rule, the bolts attaching the engine to the keelsons are too few and of too large a diameter; it would be greatly preferable to have smaller bolts, and more of them. Twelve very strong brass or copper holding-down bolts going through the vessel's bottom are sufficient, as we have already mentioned, for a side lever engine, and supposing the vessel to be a wooden one; but there should be a large number of wood screws securing the sole plate to the keelson, and a large number of bolts securing the various parts of the engine to the sole plate. In iron vessels, holding-down bolts passing through the bottom are not expedient, and then the engine has merely to be secured to the iron plate of the keelsons, which are made hollow and admit of the most effectual attachment of the engine. Where the framing is of cast iron, it is very expedient to have one piece running across the end of the engines clear of the connecting rod, so as to bind the whole of the frames together, and a cross should extend horizontally between the intermediate frames immediately beneath the paddle shaft, so as to counteract the disturbing action of the connecting rods. At the cylinder jaw, if the frame works, the best expedient appears to be the introduction of a number of steel tapered bolts, the holes having been previously bored out; and if the flanges be thick enough, square keys may also be introduced, half into the one flange and half into the other, so as to receive the strain. If the jaw cracks or breaks away, a malleable iron hoop may be applied round the cylinder, and that will in all cases be the preferable expedient, where from peculiarities of structure it can be as easily done as introducing bolts and keys. If the engines rock very much in the vessel, and are defective in other respects, it will be the preferable plan to take them out and thoroughly repair them, preparatory to their re-introduction; and the keelsons will then have to be dubbed afresh, and the sole plates fitted carefully to them. A common practice is to let the sole plates rest on the bolt heads, and then to fit in wedges all round until the vacuity is filled; but it is preferable to fit the plates down solid upon the wood, and such is the practice of the best engineers.

Rust joints are not now much used in marine engines, yet it is necessary that we should state how they are made. One ounce of sal-ammoniac in powder is added to 18 ounces or a pound of borings of cast iron, and a sufficiency of water is added to wet the mixture thoroughly, which should be done some hours before it is wanted for use. Some persons add about half an ounce of flowers of brimstone to the above proportions, and a little sludge from the grindstone trough. This cement is caulked into the joints with a caulking iron, about three quarters of an inch wide, and one quarter of an inch thick; and after the caulking is finished, the bolts of the joint may be tried to see if they cannot be further tightened. The skin of the iron must in all cases be broken where a rust joint is made, and if the place be greasy, the surface must be well rubbed over with nitric acid, and then washed with water until no grease remains. The oil about engines has a tendency to damage rust joints by recovering the oxide. Coppersmiths staunch the edges of plates and the rivets by means of a cement formed of pounded quick-lime and serum of blood, or white of egg, and in copper boilers such a substance may be useful in stopping the impalpable leaks which sometimes occur, though Roman cement appears to be nearly as effectual. It would be worth trying, however, whether the mixture would not prevent the internal corrosion of boilers, if laid on as a paint. Wire gauze smeared with white or red lead and interposed between surfaces made quite true, appears to be the best description of joint yet introduced, and has now become identified with the practice of the best engineers.

Metals used in the Construction of Engines. — The general ambition in making cylinders is to make them sound and hard; but it is expedient also to endeavour to make them tough, so as to approach as nearly as possible to malleable iron. This may best be done by mixing in the furnace as many different kinds of iron as possible; and it may be set down as a general rule in iron-founding, that the greater the number of the kinds of iron entering into the composition of any casting, the denser and tougher it will be. The constituent atoms of different kinds of iron appear to be of different sizes, and the mixture of different kinds maintains the toughness which adds to the density and cohesion. Hot blast-iron was at one time generally believed to be weaker than cold blast, but it is now found to be the stronger of the two. The cohesive strength of unmixed iron is not in proportion to its specific gravity; and its elasticity and power to resist shocks appear to become greater as the specific gravity becomes less. We have given, at page 26., the results of Mr. Fairbairn's experiments on the strength of iron, and may here add the average results of a number of experiments made in Scotland upon the same subject. The bars experimented on, were one inch square and three feet long. Coltness iron (No. 1.) bore a weight of 636 lbs., and the same iron (No. 3.) bore 649 lbs.; Gartsherrie (No. 1.) bore 633 lbs.; Shott's (No. 1.), 594 lbs.; Wilsontown (No. 1.), 706 lbs., and (No. 2.), 718 lbs.; Pintwyn (No. 1.), 681 lbs.; Calder (No. 3.), 765 lbs.; Govan (No. 3.), 645 lbs.; Bumbow (No. 2.), 734 lbs. Mixed irons are found to be stronger. Coltness and Gartsherrie (No. 1.) bore 842 lbs.; Coltness, Castlehill, Shott's, and Gartsherrie (No. 1.), 639 lbs.; Coltness (No. 1.), and Bumbow (No. 2.), 677 lbs. A mixture consisting of 2 tons Pintwyn (No. 1.), 4 tons Pintwyn (No. 2.), 5 tons of Wilsontown (No. 2.), 2 tons of Wilsontown (No. 3.), 5 tons of Calder (No. 2.), and 4 tons of Calder (No. 3.), bore 1,008 lbs.; and a miscellaneous lot of old cast iron of the cold blast manufacture, from Wilsontown, bore 1,500 lbs Numbers 3 and 4. are the strongest irons in most cases: iron remelted in a cupola is not so strong as when remelted in an air furnace; and when run into green sand it is not reckoned so strong as when run into dry sand or loam. The quality of the fuel, and even the state of the weather, exerts an influence upon the quality of the iron: smelting furnaces on the cold blast principle have long been known to yield better iron in winter than in summer, probably from the existence of less moisture in the air; and it would probably be found to be an improvement in iron-founding if the blast were to pass through a vessel containing muriate of lime, by which the moisture in the air would be extracted. The secret of making fine-skinned castings lies in using plenty of blackening. In loam and dry sand castings the charcoal should be mixed with thick clay water, and applied until it is an eighth of an inch thick, or more; the surface should then be very carefully smoothed or sleeked, and if the metal has been judiciously mixed, and the mould thoroughly dried, the casting is sure to be a fine one. Dry sand and loam castings should be as much as possible made in boxes; the moulds may thereby be more rapidly and more effectually dried, and better castings will be got, with a less expense.

In the malleable iron work of engines scrap iron has long been used, and considered preferable to other kinds; but if the parts are to be case-hardened, as is now the usual practice, the use of scrap iron is to be reprehended, as it is almost sure to make the parts twist in the case-hardening process. In case-hardening, iron absorbs carbon, which causes it to swell: some kinds of iron have a greater capacity for carbon than other kinds, and in case-hardening they will swell more; and any such unequal enlargement in the constituent portions of a piece of iron will cause it to change its figure. In some instances case-hardening has caused such a twisting of the parts of an engine, that they could not afterwards be fitted together. It is preferable therefore to make such parts as are to be case-hardened to any considerable depth of Lowmoor iron, which, being homogeneous, will absorb carbon equally, and will not twist.

Piston-rods are now very generally made of steel, and are obtained of the requisite size and quality from the rolling-mill. Steel is made almost exclusively from Dannemora iron: the bars are arranged in a furnace about 14 feet long; a layer of charcoal is spread over the bottom, then a layer of bars, and so on until about 10 tons of iron has been introduced. The top is covered with charcoal, over which is a layer of sand, and above that a layer of slush from the grindstone trough, applied wet, the object of which is entirely to exclude the air. The fire is then lighted, and in about a week the iron will have increased in weight a one hundred and fiftieth part, and be found converted into blistered steel. These bars may then be faggotted and tilted, so as to form steel articles of any size. In the operation of case-hardening the same process is carried on as in converting iron into steel, but it is only continued for such a time as to enable the charcoal to penetrate to a moderate depth. In our judgment all the malleable iron parts of a marine steam engine should be case-hardened, as they cannot then be so easily defaced, by hammer marks or otherwise, and will be much less liable to rust. The more unwieldy portions may be case-hardened by prussiate of potash, a salt made from animal substances, composed of two atoms of carbon and one of nitrogen, and which operates on the same principle as in the case of case-hardening by means of charcoal. The iron is heated in the fire to a dull red heat, and the salt is either sprinkled upon it or rubbed on in the lump, or the iron is rolled in the salt in powder: the iron is then returned to the fire for a few minutes, and immersed in water. By some persons the salt is supposed to act unequally, as if there were greasy spots upon the iron which the salt refused to touch, and the effect under any circumstances is exceedingly superficial; nevertheless, upon all parts not exposed to wear, a sufficient coating of steel may be obtained by this process. The most common plan of case-hardening consists in inserting the articles among horn or leather cuttings, bone dust, or animal charcoal, in an iron box provided with a tight lid, which is then put into a furnace, and kept hot for a period answerable to the depth of steel required. In some cases the plan pursued by the gunsmiths may be employed with convenience. The article is inserted in a sheet-iron case, amid bone dust, often not burned; the lid of the box is tied on with wire, and the joint luted with clay, and the box is heated to redness as quickly as possible, and kept half an hour at a uniform heat. Its contents are then suddenly immerged in cold water. The carbonaceous lining in the inside of old retorts is sometimes used in case-hardening with good effect.

Steel is hardened by heating and cooling it suddenly, and softened by heating and cooling it slowly. A thin blade of steel, if heated, and placed between the cold hammer and anvil, will become extremely hard; whereas a thick piece of steel would not be made hard by such a mode of treatment. Mercury has been proposed, instead of water, for hardening steel, but its use is not attended with sensible advantage. Salt and water is also used, but the articles immersed in it are liable to rust, unless afterwards steeped in lime-water. Water which has been long used for tempering is supposed to be preferable to fresh water, and if the steel is harsh the chill is taken off the water. In the case of thin edge tools the water is sometimes covered with a film of oil, but it is a question whether plain water is not preferable. The file makers medicate the water they use for tempering, and the method of doing so forms one of the secrets of the trade; but it appears probable that a little white arsenic is the chief addition they make. A common practice with some steel articles is to make them in the first instance as hard as possible, and then to soften them somewhat, or let them down, as it is called, by heating them to a certain temperature, which is indicated by the colour they assume. A pale straw colour, which is indicative of a temperature of from 430° to 450°, is the colour proper to tools for metal; a dark straw colour, 470° to 490°, is that suitable for tools for wood and for screw taps; a brown yellow, verging to a light purple, 500° to 530°, is the colour suitable for hatchets and saws; and a dark blue, 550° to 600°, is the colour for springs. Steel dies may be tempered by heating them to the colour of sealing wax, plunging them into naphtha heated to 200°, and so soon as ebullition ceases plunging them into cold water. It appears to be the prevailing opinion among experienced mechanists, that for the great majority of articles requiring to be tempered, plain cold water is the best agent, but that for small elastic works oil is preferable. For letting down large tools, a red hot muffle is a convenient instrument, and is used in the Bank of England. Steel articles may be most effectually softened by exposing them to a high heat, imbedded in a mixture of charcoal and and chalk. Steel that has been spoiled by overheating may be recovered by heating and quenching in water four or five times, carrying each to a somewhat less degree than the first excess, and finally the steel must be well hammered at a red heat, continuing the hammering until the steel is nearly cold.

Copper and zinc seem to mix in all proportions, and every addition of zinc increases the fusibility. The red colour of copper slides into that of yellow brass at about 4 or 5 oz. to the pound, and remains little altered to about 8 or 10 oz.; after this it becomes whiter, and when 32 oz. of zinc are added to 16 of copper the mixture has the brilliant silvery colour of speculum metal, but with a bluish tint. The alloys with zinc retain their malleability and ductility well, to about 8 or 10 ounces to the pound; after this, the crystalline character begins to prevail. The alloy of 2 zinc and 1 copper may be crumbled in a mortar when cold. The ordinary range of good yellow brass, that files and turns well, is from about 4½ to 9 oz. to the pound. Brazing solders may be stated in the order of their hardness — 3 parts copper and 1 part zinc (very hard); 8 parts brass and 1 part zinc (hard); 6 parts brass, 1 part tin, and 1 part zinc (soft). A very common solder for iron, copper, and brass consists of nearly equal parts of copper and zinc. Muntz's metal consists of 40 parts of zinc and 60 of copper. Any proportions between the extremes of 50 zinc and 50 copper, and 37 zinc and 63 copper, will roll and work at the red heat, but 40 zinc to 60 copper are the proportions preferred. Bell metal for large bells consists of 4½ oz. to 5 oz. of tin to the pound of copper. Speculum metal consists of from 7½ oz. to 8½ oz. of tin to the pound of copper. Tough brass for engine-work, 1½ lb. tin, 1½ lb. zinc, and 10 lbs. copper. Brass for heavy bearings, 2½ oz. tin, ½ oz. zinc, and 1 lb. copper. There is a great difference in the length of time brasses wear, as made by different manufacturers, but the difference arises as much from a different quantity of surface as from a varying composition of the metal. Brasses should always be made strong and thick, as when thin they collapse upon the shaft, and increase the friction and the wear.

Babbit's patent lining metal for bushes has latterly been introduced in the bushes of locomotive axles, and other machinery, composed of 1 lb. of copper, 5 lbs. regulus of antimony, and 50 lbs. of tin, or other similar proportions, the presence of the tin being the only material condition. The copper is first melted, and the antimony is added, with a small portion of the tin, charcoal being strewed over the metal in the crucible, to prevent oxidation. The bush or article to be lined having been cast with a recess for the soft metal, is to be fitted to an iron, formed of the shape and size of the bearing or journal, allowing a little in size for the shrinkage; drill a hole for the reception of the soft metal, say from ¼ to ¾ of an inch diameter: wash the parts not to be tinned with a clay wash, to prevent the adhesion of the tin; wet the part to be turned with alcohol, and sprinkle fine sal ammoniac upon it; heat the article till a fume arises from the ammonia, and immerse it in a kettle of Banca tin, care being taken to prevent oxidation. When sufficiently tinned the bush should be soaked in water, to take off any particles of ammonia that may remain upon it, as the ammonia would cause the metal to blow. Wash with fine pipe clay and dry, then heat the bush to the melting point of tin, wipe it clean, and pour in the metal, giving it sufficient head as it cools; the bush should then be scoured with fine sand, to take off any dirt that may remain upon it, and it is then fit for use. This metal wears for a longer time than ordinary gun metal, and its use is attended with very little friction. If the bearing heats, however, from the stopping of the oil-hole, or otherwise, the metal will be melted out.

DETAILS OF BOILERS.

Proportions. — The plate we have given of the proportions of Boulton and Watt's waggon boilers, of various powers, is a very valuable guide in the construction of all kinds of land, and even of marine boilers; for those proportions have been fully tested in practice, and found more satisfactory than any other for ordinary occasions. We may here recapitulate the chief proportions of this species of boiler.

PROPORTION OF BOULTON AND WATT'S WAGGON BOILERS OF VARIOUS POWERS.

HORSES' POWER - - - -	2		3		4		6		8		10		12		14		16		18		20		30		45	
	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.
Length - - - - - -	4	6	5	3	6	0	7	0	8	0	9	0	10	0	10	0	11	9	12	8	13	6	16	0	19	0
Breadth at water-line - - -	3	2	3	4	3	6	3	9	4	0	4	3	4	6	4	9	5	0	5	2	5	4	5	6	6	0
Height - - - - -	4	1	4	4	4	7½	5	1½	5	6	5	9½	6	0	6	2½	6	6	6	8	6	10				
Height of water - - - -	2	6	2	8	2	10	3	3	3	6	3	8	3	9	3	10	4	0	4	1	4	2	4	9	5	6
Radius of crown - - - -	1	7	1	8	1	9	1	10½	2	0	2	1½	2	3	2	4½	2	6	2	7	2	8	2	9	3	0
Heating surface - - - -	30	0	38	0	46	0	64	0	83	0	100	0	118	0	138	0	156	0	176	0	201	0	297	0	438	0
Height of flue round boiler - -	1	9	1	10	1	11	2	4	2	9	3	1	3	2	3	5	3	7	3	9	3	11	4	0	4	9
Width of flue round boiler - -	0	9	0	9	0	10	0	10	1	0	1	0	1	1	1	1	1	2	1	2	1	2	1	4	1	3
Heating surface per horse power -	15	0	13	0	11	0	10·7		10·2		10	0	9·8		9·8		9·7		9·8		10	0	9·8		9·6	
Capacity of steam room in cubic feet	17½		22⅓		23⅓		34⅓		50		64		72		80		97		106		114·7		190		268	
Contents of water in cubic feet -	37		40		56		76		103		134		162		205		238		270		299		282		342	

The 30 and 45 horse power boilers contain internal flues.

A pound of coal raises about 9 lbs. of water into steam, in the majority of good land boilers; but in some of the Cornish boilers, a pound of coal raises 12 lbs. of water into steam, or a cwt. of coal evaporates about 20 cubic feet of water. The weight of fuel burned on each square foot of grate-bars varies very much in different boilers; in waggon boilers it is about 12 or 13 lbs., in Cornish boilers from 3½ to 4 lbs., and in locomotive boilers about 80 lbs. The number of square feet of heating surface for each square foot of fire grate, is in waggon boilers from 14 to 15 square feet; in Cornish boilers, about 40 square feet; and in locomotive boilers, upwards of 70 square feet. Reckoning an engine of 73 inches diameter of cylinder, and 7 feet length of stroke at 217 horses' power, the area of fire grate in the most judiciously constructed marine flue boilers, such as that of the Great Western, is ·46 of a square foot,—the engine working expansively from one third to one fourth of the stroke. The heating surface in this boiler is 8·8 square feet per horse power, if the horse power be reckoned by our rule, page 107., so that the heating surface is 19 times the area of the grate surface; and if the consumption of fuel be taken at 6 lbs. per horse power per hour, as it was very nearly, there will be about 13 lbs. of coal consumed per hour on each square foot of fire grate. In the tubular boilers latterly introduced into steam vessels, the proportions are somewhat different. The boilers of the *Braganza*, reckoning the power of the engines at 289 horses' power, have only ·39 square feet of fire grate per horse power, while the heating surface is 11·98 square feet per horse power; but the grate surface, in this case, admits of a ready increase by lengthening the bars. This is at the rate of 30·71 square feet of heating surface for one square foot of fire grate; and if the consumption be taken at 6 lbs. per horse power per hour, there will be 15·38 lbs. of coal consumed per hour on each square foot of fire grate. The grate surface per horse power in the tubular boilers of the *Tagus* is ·38 square feet, and the heating surface is 7·73 square feet, which is at the rate of 20·39 square feet of heating surface per square foot of grate. In the tubular boilers of the *Sydenham*, the proportion is 21·64 square feet of heating surface per foot of grate, but the proportion of grate per horse power is larger than in the *Tagus*. In the tubular boilers of the *Ocean* steamer (232 horse power) the grate surface per horse power is ·59 square feet, the heating surface 13·48 square feet per horse power, which gives 22·84 square feet of heating surface per square foot of grate. The consumption of coal per horse power per hour is 8·68 lbs., which is at the rate of 14·71 lbs. per square foot of fire grate per hour; but if, for the sake of comparing it with the previous examples, the consumption be taken at 6 lbs. per horse power per hour, as would be the case if the engine were worked more expansively, then the consumption of coal per hour on each square foot of fire grate would be 10·17 lbs. These particulars may be tabulated thus:—

Vessels.		Makers.	Heating surface per nominal horse power, as estimated by Table, pp. 96, 97.	Grate surface per horse power.	Heating surface per square foot of grate surface.
Great Western	Flue boilers -	Maudslay	8·8	·46	19
Braganza -	Tubular -	Bury	11·98	·39	30·71
Tagus - -	Tubular -	Miller	7·73	·38	20·39
Ocean - -	Tubular -	Horton	13·48	·59	22·84
Sydenham -	Tubular -	Woolwich			21·64
Phœnix - -	Tubular -	Penn	9·1	·44	20

The boilers of the *Phœnix*, by Messrs. Penn, are represented in one of our plates.

The amount of steam room in boilers varies very much. Waggon boilers of 2 horses' power, it will be observed, have about 8 cubic feet of steam room per horse power, and the proportion diminishes as the size of the boiler is increased, until at 45 horse power the steam room is about 5 cubic feet per horse power. In the tubular boilers of marine engines, the proportion is less than this. The tubular boilers of the *Braganza* have about 3·44 cubic feet of steam room per horse power; those of the *Ocean*, 2·58 cubic feet, while some have as little as 1·79 cubic feet; but these last are addicted to priming. The proportions of half a square foot of grate surface, 10½ to 11½ square feet of heating surface, and 3 cubic feet of steam room per horse power, seems to answer very well for tubular boilers when the engines work expansively through one third or one fourth of the stroke. In these estimations, the whole of the tube surface is reckoned as effective surface.

The proper arrangement of heating surface in a boiler, so as to prevent the overheating of the plates, is very important. Surfaces exposed to a high temperature should always be so made that the steam may disengage itself easily from the metal; for if it be retained in contact with it for any considerable time, the access of the water will be prevented, and the plate will become overheated in consequence. The vertical sides of high furnaces are often greatly damaged from this cause: the steam is retained among the landings of the plates and other irregularities of surface, and the sides of the surface become buckled and drawn from the iron becoming overheated. It is very expedient, therefore, to make all furnaces of marine or locomotive boilers wider at the bottom than at the top, after the fashion shown in the plate of the *Phœnix* steamer, by Messrs. Penn; the landings of the plates should also be made so as to prevent the possibility of steam being retained in them. The aftermost tube plate should be set at a slight angle to facilitate the liberation of the steam; and as the tubes will thus be somewhat off the horizontal, any water which may escape by leakage will run into the furnace, instead of incommoding the firemen by running out of the smoke-box doors.

Construction of Boilers. — The whole of the shells of boilers intended to withstand any considerable pressure, should be double rivetted, with rivets 2¾ inches from centre to centre, the weakening effect of double rivetting being much less than that of single rivetting. The furnaces above the line of the bars should be of the best Lowmoor or Staffordshire scrap plates, three eighths thick, and each furnace above the bars should consist of three plates, one for the top and one for each side, the underseam of the side plates being beneath the level of the furnace bars. The tube plates of tubular boilers should be of the best Lowmoor iron, seven eighths to one inch thick; the shells should be of the best Thornycroft S crown iron, or of Staffordshire iron, of good quality, and seven sixteenths thick at the least. Angle iron should not be used in any part of a boiler, as in the manufacture it becomes reedy, like wire, and is apt to split in the direction of its length. It is a much safer dependence to bend the plates, if it be carefully done, and without any more sharp turns than can be helped, but it is convenient to use a little angle iron about the furnace mouths, which should be of the very first quality. The whole of the plates of boilers should be punched with a double punch, one nipple of which enters the hole last punched, while the other punches the hole; and it is very convenient to have the punching press provided with a travelling table, whereby the operation of punching and paring the edges of the plates is made a self-acting one. The use of drifts and screw-jacks in putting the parts of boilers together, should not be permitted. The rivets should be of the best Lowmoor iron, eleven sixteenths in diameter. The whole of the work should be caulked both inside and outside, so far as it is accessible; the parts may then be washed over with a solution of sal ammoniac, and the rivets and landings above water painted over with a mixture of whiting and linseed oil, as mentioned at page 202. It is very desirable that the space between the furnaces and tubes of tubular boilers should be sufficiently large to enable a man or boy to get in. The bend joining the top of the furnace at the after end with the bottom of the tube plate, is very liable to get burnt away; and its repair will be most difficult, unless made accessible from the inside to hold on the rivets. The boilers of the *Sydenham*, page 65., are very judiciously formed in this as well as in most other respects; it appears expedient, however, to shield this and another such exposed part, where the heat acts injuriously upon the iron, by means of fire blocks moulded to the place, and secured by nuts sunk into dovetailed recesses in the substance of the block, which recesses are finally filled up with fire clay. In new boilers even, such an application is most expedient in situations in which injury to the iron, from the impact of flame, is experienced or apprehended. The plate on the furnace side of the water-space at the end of the boiler should be inclined considerably towards the tubes to facilitate the ascent of the steam; and it appears to be the preferable way to round off the top of the chamber leading from the furnace to the tubes, as in the case of the *Braganza*'s boilers, shown at page 67. It appears preferable, too, to zig-zag the tubes sideways, as in the case of the *Braganza*'s boilers; as a greater strength of iron is thus got between the holes in the end plates, without diminishing the facility of scaling the tubes, or introducing any instrument down between them to keep the spaces clear.

Tubing and staying of Boilers. — The tubes of boilers are most generally secured at the ends by means of ferules driven tight into them, the holes in the end plates being usually countersunk, and a corresponding projection being made on the ferules. The ferules next the furnace are best made of steel, while, for the other ends, malleable iron ferules answer as well. The tool in which the ferules are made consists of three pieces; one piece is set in the anvil, and consists of a flat plate with a nipple on it, rising to half the depth of the ferule, and rounded at the corners; the next piece consists of a ring furnished with a handle, and with its lower edge recessed slightly into the flat plate so as to steady it, and this ring is larger in its internal diameter than the nipple by twice the thickness of the ferule; the last piece consists of another nipple made like the first, but formed with a head like a punch. A small hoop is formed by welding a piece of steel or iron, and is dropped into the space between the interior of the ring and the lower nipple; the upper nipple is then forced down by striking the punch head with a forge hammer, whereby the ferule is moulded to the right form: the parts are finally taken asunder, whereby the ferule is liberated.

In brass tubes the use of ferules appears to be indispensable, but in the case of stout iron tubes, such as Russell's patent boiler tube, they are unnecessary; and the best plan, when iron tubes are used, appears to be to widen one end of the tube slightly, and to drive the tube in from the front of the boiler into both tube plates, the holes in the front plate being made one sixteenth wider than those in the back plate, and the tube being widened correspondingly. Before the tubes are driven in, the holes in the tube plates must be slightly countersunk, and the tubes must finally be carefully rivetted in. It will be expedient to screw a few of the tubes into the tube plates instead of rivetting them, so as to serve as stays, and also as abutments to rivet the rest of the tubes against. The screwed tubes should be left a little longer than the others; and thin nuts made of boiler plate should be screwed upon the projecting ends to prevent leakage, and add to the security of the staying. In fitting in the tubes in this way, great care is necessary to make them perfectly tight; and it will be expedient to turn the ends slightly in the lathe to give them a trifling taper, and make them all precisely of the same size. In driving them in, each tube should not be driven home at once, as that will spring out the iron between the holes, but they should be all fitted in first with the common chipping hammer, and when thus all equally fitted, they should be driven home by a heavy hammer, or ram. The countersink in the holes must be but slight, and must be filled rather by rivetting up endways than by rivetting over. In some cases, boilers are made with collars rivetted on the tubes immediately behind the tube plates, but this plan is attended with the objection that a tube cannot be renewed without taking the boiler asunder; and with the still greater defect, as it appears to us, that the ends of the tubes will be liable to get burned away in consequence of the internal collar preventing the access of the water. Boilers formed on this plan, therefore, will, we believe, be found to become leaky at the ends of the tubes; and unless stayed, independently of the tubes, the tube plates will be forced asunder by the pressure of the steam.

We can best illustrate our views upon the staying of boilers by taking a particular case, and we may suppose that it was required to stay the boilers of the Phœnix, represented in one of our plates, in such a way as to be safe under a very high pressure. To do this, it would be necessary to stay the sides of the furnaces to one another by three stays in the direction of their height, and five or six stays in the direction of their length. The highest row of stays would run along where the crown of the furnace joins the side, and the lowest where the bottom of the furnace joins the side, the third being situated in an intermediate position, so as to be shielded as much as possible by the furnace bars from the action of the heat. The bottom of each furnace should be stayed to the bottom of the shell by two rows of stays, and the tops of the furnaces should be secured by means of arched malleable iron bars, to which the plate would be stayed as in locomotive boilers. These arches should touch the plates only at the points at which the stays go through, and their lower edges should be sharpened away in order to facilitate the disengagement of the steam; they may be joined together athwartships, or made in the same piece, and from the part opposite each water space a row of stays should run to the top of the boiler. To enable these stays to pass, a perpendicular row of tubes must be left out opposite each water space, which will have the further advantage of enabling the water to circulate with greater facility. The steam chest should be stayed both fore and aft and across, with stays pitched 18 in. or 2 ft. apart; a row of athwartship stays should run horizontally across immediately under, and another immediately above the tubes, and from the ends of the stays of the superior, to the ends of those of the inferior row, vertical bars should ascend between the tubes and the shell, to which the shell may be stayed while the sides of the water-space between the end of the furnaces and the end of the boiler are stayed with stays of the same dimensions and pitch as those of the furnaces. These stays may consist of 1¼ in. bolts of the best scrap iron tapped through both plates, and in the furnaces they should have thin nuts of boiler plate on their ends; but where stay bolts penetrate the boiler shell, they may have heads on the outside of the boiler. The whole of the long stay bars should be fixed in their places, not with cutters, as is the common fashion, but with rivets; they should be as it were built into the boiler, so that the safety of the boiler cannot be endangered by the decay or accidental detachment of a cutter or pin. Where stays join on to the root of the funnel, they must be continued through it by placing short stays in the inside, and wherever a large perforation in the shell of a boiler occurs, from the application of a steam chest or otherwise, a sufficient number of stays should be put across the opening to make the strength as great as if there were no perforation.

Respecting the strength of boilers, we have already made some observations at pages 82. and 83., where we have stated that it is expedient to keep within a load of 3000 lbs. upon the square inch of iron in boilers in actual use. The breaking strain of good iron is about 60,000 lbs. on the square inch, but the best malleable iron will not bear a greater load than about 18,000 lbs. on the square inch, without permanent derangement of structure, or 17,800 lbs., as is stated at page 102. Tredgold gives a rule for determining the strength of cylinders, cylindrical boilers, and other such vessels, which gives proportions not far from those which are advisable. It is this:—Multiply 2·54 times the internal diameter of the cylinder by the greatest force of steam on a circular inch; divide by the tensile force the metal will bear without permanent derangement of structure; the result is the thickness in inches. In practice, the iron of boilers has sometimes to sustain a greater strain than what is indicated in this rule. The utmost strain to which iron can be safely subjected in machinery, is 4000 lbs. on the square inch, and this strain is approached in locomotive engines. A cylinder 12 in. diameter, with a piston-rod 1¾ in. diameter, and with steam of 80 lbs. on the square inch, bears a tensile strain of 3766 lbs. on the square inch. Upon the iron of the boiler the strain is still greater, being about 5000 lbs. on the square inch. If the plate be $\frac{5}{16}$ thick, it will require 3·2 in. in length of the boiler to make a square inch of sectional area, and if the diameter be 39 in., the separating force will be $39 \times 3·2 \times 80 = 9984$ lbs. But this strain is borne by a square inch of sectional area on each side of the boiler, wherefore the strain on a single square inch of sectional area is half of this, or about 5000 lbs. This takes no account of the support derived from the boiler ends, but in long boilers the support derived from the ends is but small, and is not equivalent to the weakness caused by the rivet holes. A strain at all approaching that upon locomotive boilers would be most unsafe in the case of marine boilers, on account of the corrosion to which they are subject. All boilers should be proved with water when new, to three or four times the pressure they are intended to carry, and they should be proved occasionally by the hand-pump, when in use, to detect any weaknesses that corrosion may have created. In connection with the strength of boilers, we may state that the "Administration des Ponts et Chaussées," in France, has fixed the following formula for the dimensions of safety valves for stationary engines. d = diameter in centimètres; c = the total heating surface in square mètres; n = the effective pressure in the boiler in atmospheres;

$$d = 2·6\sqrt{\frac{c}{n - 0·412}}.$$

A mètre is 3·28 feet, and a centimètre is the hundredth part of a mètre, or ·0328 of a foot. Every marine boiler should be provided with a safety valve, the action of which is independent of that of the stop valve, so that though the stop valve becomes deranged, the safety valve of that boiler will nevertheless act.

It is very desirable that a marine boiler should be fired from the one end only, as in the case of the Phœnix, a material saving of room being thereby effected in the ship. In that case, too, there is no inducement to use more than one funnel. Funnel plates are usually 9 feet long and $\frac{3}{16}$ thick, and if there be a platform for coal over the boilers, it will be the best economy to make it of the same thickness, but the other parts of the bunkers may be made of sheet iron weighing 8 lbs to the square foot. The dampers should not be in the funnel, but in the top of the uptake, so that they may be closed if the funnel is carried away. It is expedient to put two hoops upon the funnel for the attachment of the funnel shrouds, so that the funnel will not be carried overboard should the bolts joining the lugs of one hoop break, or should the funnel break across at the top hoop, as has sometimes happened from the corrosive action of the steam escaping at the waste steam pipe. A high angle iron cooming should surround the funnel, on the deck, outside of which should rise a sheet iron casing, and this sheet iron casing should be rivetted to the cooming or made quite tight thereto, so as to prevent the possibility of water leaking down on top of the boiler. Over the casing, another short piece of casing rivetted to the funnel should descend for about a foot, so as to prevent the spray from entering between the casing and the funnel, and thus getting down upon the boiler. The usual height of the funnel of sea-going steamers is from 40 to 50 feet.

Miscellaneous Remarks about Boilers.—All the rough nuts about a steam vessel which require to be screwed and unscrewed frequently, such as the bolts of the man-hole and mud-hole doors of the boiler, should have large square nuts, and the bolts should be strong and have coarse threads. Hexagonal nuts speedily become round in the hands of the firemen, by whom the mud-hole and man-hole doors are generally taken off, and fine threads soon get stripped and overrun. It is much the safest way to put on both mud-hole and man-hole doors from the inside, with cross bars on the outside to keep them closed. The plan sometimes followed, of putting on mud-hole doors from the outside, and securing them by one or two bolts, is a practice we have already reprehended as full of danger, as, if the thread strips or the bolt breaks, the door will fly off, and the boiling water rush out, scalding every one in the vicinity. Mud-hole doors of this kind, even if they leak, cannot be screwed up to tighten them when the steam is up, as there is a perpetual risk, in tightening the doors, of stripping the thread or breaking the bolt.

We have already, in pages 84. and 93., made some remarks upon the corrosion of boilers, and have here but little to add upon the subject. The tops and steam chests of boilers, and the bottoms of the ash-pits, are the first parts to give way. The steam-chest wears chiefly from internal action; in some cases the iron exfoliates in the form of a black oxide, which separates in flakes like the leaves of a book; while in other cases the iron is, as it were, gouged away, and the heads of the rivets are worn off, as if by an acid. It is most important that a remedy should be found for this evil, and it appears probable that by painting the interior of the boiler with successive coats of Roman cement, or of some of the calcareous cements which resist the action of water, the internal corrosion of the boiler might be prevented. Canvass soaked in liquid cement has been proposed, but it is questionable whether the canvass might not on some occasion come off, and if it got into the mouth of the safety valve orifice, it might cause the boiler to burst. The ash-pits are worn away chiefly by the wetting of the ashes in the stoke-hole, and it is expedient to apply shield plates to those places when the boilers are made, which plates only will be exposed to wear, and may be easily renewed, leaving the ash-pits untouched. The best method of setting boilers appears to be to set them on a platform, and care must be taken that no projecting copper bolts touch the boilers in any part, as they will be very likely to corrode the points of contact into holes. The platform may consist of 3-inch planking, laid across the keelsons, nailed with iron nails, and caulked and puttied like a deck. The surface may then be painted over with thin putty, and fore and aft boards of about half the thickness may then be laid down—the heads of the nails being well punched down. This platform must next be covered with mastic cement, and the cement must be caulked beneath the boiler by means of wooden caulking tools, so as completely to fill every vacuity. Coomings of wood must next be laid round the boiler, to confine the cement; and the space between the coomings and the boiler must be caulked full of cement, and be smoothed off with a slope on the top so as to throw off any water that may chance to fall upon it. Many cements suitable for the setting of boilers are sold ready made; the following is one of the compounds sometimes used:—To any given weight of sand, or pulverised earthenware, add two thirds of such given weight of Portland, Bath, or any other similar stone, pulverised. To every five hundred and sixty pounds weight of these earths, so prepared, add forty pounds weight of litharge, and, with the last-mentioned given weights, combine two pounds weight of pulverised glass or flint-stone. Then join to this mixture one pound weight of minium and two pounds weight of grey oxide of lead. The composition being thus mixed, pass the same through a wire sieve, or dressing machine, of such a fineness as may be requisite for the purpose intended, preferring a fine sieve, when the composition is to be used for works that require a fine, smooth, or even surface. It is now a fine and dry powder, and may be kept open in bulk or in casks for any length of time, without deterioration. When this composition is intended to be made into cement, it is spread upon a board or platform, or mixed in a trough ; and to every six hundred and five pounds weight of the composition are added five gallons of vegetable oil, as linseed oil, walnut oil, or pink oil. The composition is then mixed in a similar way to mortar ; it is afterwards subjected to a gentle pressure by treading upon it, and this operation is continued until it acquires the appearance of moistened sand. The cement should be used the same day the oil is added, otherwise it will fix or set into a solid mass.

The large rivets sometimes used as stays for the shells of boilers, are objectionable, as the heads very often come off, and if the fracture be between the boilers in a position not accessible from the outside, it will be necessary to empty the faulty boiler of its water, in order to repair the defect. The sides of furnaces should always be made to incline to each other in the manner already mentioned, so that the crown is not so wide as the fire bars, and it is a good arrangement to place the bars adjoining the sides close against the sides throughout their length, so as to leave no air space in that situation. By this arrangement the intensity of the heat acting immediately against the plates of the sides is diminished. A crack in a plate is most conveniently closed, by boring several holes along its length, and closing them with rivets having large heads which cover over the defect. If a patch be applied to the top of a furnace or flue, it is better to apply it from the inside of the boiler rather than from the flue, as in the latter case a recess is left into which deposit falls, and a hole is likely then to be burnt again in the same place. If the furnace mouth be contracted by bending in the sides of the furnaces, as is the general practice, it is necessary to be very careful that scale does not accumulate in these corners, else they will be very liable to be burnt into holes. The waste steam pipe should be set into a faucett at the bottom, instead of being constructed with a flange, as the neck of a flange will be broken by the movement of the funnel when the vessel rolls. The waste steam pipe should be as high as the funnel, as, if lower, the waste steam continually striking against the funnel wears it out in that part very rapidly. The pipe for conducting away the waste water from the top of the safety valve, should lead overboard, and not into the bilge, as the steam which passes through it when the steam is blowing off is inconvenient if directed into the ship. Respecting fire bridges, the preferable practice, on the whole, appears to be to construct them of brick rather than to make them water bridges, as with water bridges there is often trouble from the cracking of the plates. If water bridges, however, be used, they should be made with a great inclination in the breadth of the furnace, to facilitate the escape of the steam, as in the boilers of the Thames and Medway, page 61., or of the Phœnix, page 52. Flame bridges have been introduced into the furnace flues of steam vessels on some occasions, consisting of a pile of fire brick, between which and the sides of the flue only a space of about three inches is left for the flame and smoke to pass through, and the flame is spread in a sheet over the interior of the flue. Where the flue is very large, the use of a flame bridge appears to be expedient, and in land boilers with large internal tubes, its use has been attended with beneficial results, but in the majority of marine boilers we believe that it will prove of but little service. Hanging bridges, consisting either of brick or sheet iron, descending from the top of the flue, as explained at page 65., are very beneficial in the majority of flue boilers, but are inapplicable in the case of tubular boilers. A Venetian damper, however, or a perforated plate applied at the end of the tubes, would probably produce the same effect, as it might be made to retain the heat in the upper portion of the tubes by only opening it partially. Dampers of the Venetian blind description are used upon the South Western Railway ; their structure is more fully explained in our remarks upon the details of locomotives.

LOCOMOTIVE ENGINES.

General features of the Boiler. — The boiler is the most important part of a locomotive engine, and the useful effect of the machine depends in a great degree on the boiler being capable of generating the requisite quantity of pure steam, without requiring the draught of air and flame through the fire and tubes to be accelerated or forced excessively. The fire-box is that part of the boiler in which the heat is generated and partially absorbed, the remaining absorption taking place in the flue tubes, which convey the products of combustion from the fire, through the water, to the smoke-box, whence they are dissipated in the atmosphere. Of course the more nearly these products of combustion, at their entrance into the chimney, are found to have been cooled down to the temperature of the water in the boiler, the more economical in fuel the boiler will, *cæteris paribus*, be. To obtain the utmost economy in this way, the superficial surface of the tubes has been increased to the utmost extent, by enlarging the diameter and increasing the number and size of the tubes. The boiler of Bury's 14-inch* engine contains 92 tubes of 2$\frac{1}{8}$ in. external diameter, and 10 ft. 6 in. long ; the boiler of Stephenson's 15-inch engine contains 150 tubes of 1$\frac{5}{8}$ in. external diameter, and 13 ft. 6 in. long. It will therefore be seen that the superficial surface in Bury's tubes is, comparatively, rather small, but yet the production of steam is found to be sufficiently copious, with a blast-pipe of rather more than the average diameter; on the other hand, notwithstanding its great surface, Stephenson's boiler is found to require a smaller blast-pipe than usual. It seems highly probable that the extra intensity of blast requisite in the latter case consumes so much power to produce it, as completely to countervail the economy of fuel consequent on the very complete abstraction of the heat, by the great length of tubes in proportion to their diameter.

In an experiment tried by Mr. Stephenson, the heating surface of the fire-box, where the heat is received by radiation, was found to be more effectual than the tube surface, where the heat is received by conduction, in the ratio of 1 to 3, and hence the heating surface of a locomotive is sometimes estimated as the surface of the furnace plus one-third that of the tubes.

The shell, which is cylindrical, is attached to the smoke-box and fire-box by angle iron ; the end of the shell next the smoke-box is closed entirely by the tube plate, but at the smoke-box end the water has free access quite round the internal fire-box, one side of which forms the tube plate. The shell, external fire-box, and the smoke-box are always of iron, the thickness of plate being $\frac{5}{16}$ in. in ordinary boilers of 3 ft. to 3 ft. 4 in. diameter, though in some cases it is $\frac{3}{8}$ in. ; the pitch of rivets is 1$\frac{7}{8}$ in., and the diameter of rivets $\frac{11}{16}$ in. The shell is sometimes made with flush joints, a band of iron covering the joint attached by two rows of rivets. The boiler plates should have their fibres running round the boiler instead of in the direction of its length, as the plate is somewhat stronger in that direction. The boiler is secured endwise by longitudinal stays, which are fastened by cutters to jaws attached to the end plates. We have already made some remarks upon the strength of boilers, at pages 82, 83. 230.

The blast pipe is the eduction pipe diminished in area at the mouth to such a degree as to cause the steam to issue with a great velocity, whereby a powerful draught through the fire is maintained by the steam rushing up the chimney. The area of the mouth of the blast pipe varies in different engines, but an area of $\frac{1}{22}$d of the area of the cylinder is a common proportion. A variable blast pipe, the orifice of which may be increased or diminished in area, is now much used. One arrangement for this purpose consists of the application of a regulator plate at the top of the blast pipe, with a hole through the centre of the plate, through which the nozzle of the blast pipe passes. When this regulator plate is closed, the whole of the steam has to ascend through the central nozzle ; but when the regulator is open, or partly open, a part of the steam escapes through the holes in it. Another plan consists in the application of a movable plug within the blast pipe, which may narrow the escape orifice to an annular space of small area, the plug being raised or lowered by a lever and rod. Stephenson's method of contracting the blast is shown in the sectional drawing of one of his engines, given among our plates. It consists in making the nozzle of the pipe conical, and forming it to slide within the upright pipe, whereby an annular space is left for the escape of the steam around the nozzle when the nozzle is lowered. This appears to be a preferable plan to either of the preceding.

The man-hole, or entrance into the boiler, consists of a circular or oval aperture of about 15 in. diameter, placed by Bury at the summit of his dome, and by Stephenson in the front part, a few inches above the cylindrical part of the boiler. The cover that closes this aperture in Bury's engine also contains the safety valve seats, thus simplifying the construction by preventing the necessity of an independent aperture and cover for the safety-valves, as in Stephenson's engine, where the safety-valves are placed independently on the top of the dome. The steam-tight joint of the manhole cover is made in Bury's engine by a single thickness of canvass, smeared with red-lead; and the joint is not liable to become defective or leaky, because the surfaces are turned true and smooth, both on the cover and its seat. When these surfaces have not been made true in this manner, it becomes requisite to use a number of thicknesses of canvass, or other material, to form the joint; and the action of the steam soon rotting away the soft substance, a leakage is caused through the joint, which makes repair indispensable. The small domes are of the same form as those used on the Grand Junction Railway, which are cylindrical vessels of about 20 in. diameter, and 2 ft. in height, with a semiglobular top, are generally made of plate-iron, about $\frac{3}{8}$ in. thick, welded at the seam, and with the flange at the bottom turned out of the same piece. In some cases, domes of this form have been constructed of cast-iron, abont $\frac{3}{4}$ in. thick, but they have been found objectionable from their top weight, and they cannot be considered as altogether safe from explosion.

The steam whistle is generally placed upon the fire-box dome within convenient reach of the engineer. It consists of a cock (*fig.* 324.), opening by four side holes into an annular chamber, whence the steam escapes through an annular aperture about $\frac{1}{64}$ in. in width, striking in its exit the edge of a bell, fixed by a stem to the cock, whereby the sound is produced. The edge of this bell should be about $\frac{1}{32}$ of an inch thick, and should be exactly over the opening, so that the issuing steam may impinge directly upon it.

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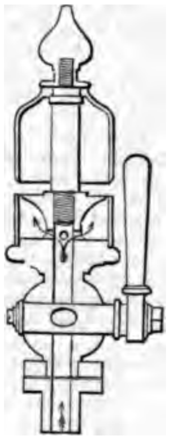
* This dimension is the diameter of cylinder, by which dimension locomotives are distinguished.

The metal should be of similar composition to that of clock bells. The whistle is sometimes jointed by running melted lead between its flange and the dome-plate; but it is better to fit the surfaces so truly together as to be steam-tight merely with the assistance of one thickness of fine canvass coated with read lead or cement, for lead will always be found to decay by contact with high-pressure steam, making continual renovation necessary. This remark equally applies to the other joints connected to the shell of the boiler, such as the gauge-tube, blow-off cocks, and feed-pipes.

Fig. 324.



STEAM WHISTLE.

To save the steam which is formed when the engine is stationary, a pipe is fitted to the boiler which conveys the steam at such times to the tender, where it heats the water and is itself condensed. This method of disposing of the steam is beneficial in descending inclined planes, when more steam is formed than is required for the use of the engine. A cock for emptying the boiler is usually fixed to the bottom of the fire-box; this cock should not be placed at the front end of the fire-box, as the foul water blown out of the boiler is thrown over the gearing, which is injured by the sand getting into the bearings.

Fire-box.—Iron fire-boxes have been extensively tried by Bury and others, and in cases where the plate-iron of which they were formed has been of a peculiarly perfect texture, and not liable to laminate or crack under the action of the heat, they have been found to answer exceedingly well, and not only to be much cheaper than copper, but also to last at least twice as long before requiring renewal. If the materials be very carefully selected, the use of iron fire-boxes will be found productive of economy, if only used in situations where pure water is obtainable. The duration of ordinary copper fire-boxes depends in a great measure upon the original texture of the copper, which ought to be rather coarse-grained than rich and soft, and also particularly free from irregularity of structure and lamination. Considerable advantages have been found to arise from increasing the capacity of the fire-box, more especially its depth, which ought to be such as to allow of the requisite quantity of coke being placed within it without reaching above the mouths of the lower tubes, a fault which would cause the smaller pieces of coke to enter and block up the tubes, to the manifest deterioration of the draught, and diminution of the efficacy of the engine. The heating surface in the fire-box being of an extremely valuable and efficient nature, and the extensive area of fire-bar surface being very conducive to freedom of draught, we are induced to question whether the large square fire-box is not *pro tanto* preferable to the round one, which must necessarily be very small, except on the 7-feet gauge, in which case the round fire-box offers decided advantages. The square fire-box is generally made of iron, ⅜ in. to ½ in. thick in every part except the tube plate, which has been from ⅝ in. to ¾ in.; but experience has shown considerable advantage in making the tube-plate ⅞ in. thick, as this great strength prevents the spaces between the tubes from being compressed, and the tube holes rendered oval, in the processes of drifting and feruling the tubes; however, this evil will be found to exist, even with a ⅞ in. tube-plate, if the tube holes be placed in too close contiguity, as has been found the case in several of Stephenson's engines; and, from practical observation, we find that ¾ in. should be the minimum distance between any two tubes. The sides, back, and front below the tubes, of the square fire-box, are stayed at intervals of 4½ in. to 5 in. with either copper or iron stays, screwed through the outer case into the fire-box, and securely rivetted; but, as the rivetting within the fire-box is found to decay rapidly, from the action of the heat, Mr. Dewrance, of the Liverpool and Manchester Railway, has adopted, with good results, stays formed with a large square head, and screwed from within the fire-box outwards, the square head projecting 2 in. into the flame. Iron stay-bolts for the fire-box are found to last nearly as long as copper, and, from their superior tenacity, are often considered preferable. Until lately, it had been supposed that round fire-boxes possessed such advantages in point of strength over square ones, owing to their arched form, that they were capable of resisting the pressure of the steam without the use of stays; but experience has shown that, whatever be the shape, a fire-box must be stayed more or less to render it safe, for the shell of the fire-box is liable to be wasted so much by the heat, that it is not safe to depend altogether upon the strength its form confers, especially as the form will be changed if the boiler be suffered to become short of water. In round fire-boxes, the sides near the crown part generally suffer most from waste: these portions are now provided with stays by Messrs. Bury, Curtis, and Kennedy, who are the main supporters of round fire-boxes; and with this provision the round fire-boxes are necessarily the stronger. The roofs of all fire-boxes require to be stayed by cross-bars; but the bars are required to be both stronger and more numerous for the square fire-boxes, and should always be carefully made of wrought-iron, and very carefully fitted before being bolted on. Stay-bars of cast-iron have been employed, on account of their cheapness; but, having led several times to accidents from explosion, they are now discarded. These bars are only in contact with the fire-box at the part around the rivets, and in all the other parts they permit the access of the water below them. It is advisable to bring these bars to an edge on the under side, so as to facilitate the escape of the steam. In Sharp and Roberts's engines, the fire-box is made of three plates; the tube plate and front plate have their edges bent over, and to these are attached a single plate which forms the crown, and two sides of the furnace. The interior fire-box is joined at foot to the exterior by a Z shaped iron, which forms the bottom of the water space, and is preferred, inasmuch as it leaves a wide water space, and is easily cleaned. The outer and inner fire-boxes are joined round the furnace door, which is double, to prevent inconvenient radiation. The external fire-box has sometimes a semi-cylindrical top, joined by turning over the sides like an arch, and sometimes a dome-shaped top.

The fire-bars have always been a source of much expense in the locomotive engine, as they burn out very rapidly, and have to be often renewed; from the rapid combustion going on over their upper surfaces, they become heated intensely throughout, causing them to throw off scale, and to bend under the weight of the fuel. The best remedy has been found to consist in making the bars very thin and deep, so as to keep their lower edges exposed to a cooling draught of air, and to diminish the area of metal conducting heat downwards from their heated upper edges. Thin fire-bars admit of being placed nearer together than thick ones, thus offering no increased impediment to free draught, while preventing the loss of small pieces of unburnt coke, which might otherwise drop through into the ash-box, and be wasted. Fire-bars have given much satisfaction when made 4 in. deep (parallel) and full ⅝ in. thick on the upper edge and ⅜ in. on the lower edge. The frame carrying the fire-bars has often been made capable of being dropped on the instant, with its fire-bars and fire, into the ash-box, or upon the road, by means of catches drawn back by levers; but though the fire-bar frame is thus left unsupported, very often it will not drop, and even cannot be forced down out of its place, owing to the clinkers and tarry products of combustion forming an adhesive binding between its edge and the fire-box; it has accordingly been found best to support the fire-box frame permanently, and when any cause requires the sudden withdrawal of the fire, to lift the fire-bars singly out of place, by means of the ordinary dart. It is necessary to place the fire-bars with their upper surface about 3 in. higher than the bottom of the water-spaces, which, by this means, will be allowed to contain quiescent water, ready to retain without injury any deposit that subsides from the water, and the water-spaces should be periodically cleansed, by means of the mud-holes placed opposite the edge of each water-space in the lower part of the outer fire-box shell. These mud-holes are made water-tight by means of either a brass plug simply screwed in and with a slight taper, or by a door applied with a soft packing on its face, and screwed up with a bridge-piece and bolt, making the joint on the internal surface of the outer shell, the hole and door being made sufficiently oval to enable the door to be introduced into the water-space. The latter plan often gives rise to inconvenience, from the joint being found leaky when the steam is raised, rendering it necessary to drop the fire, and empty the boiler, before it can be renewed. In some very large square fire-boxes, such as those used on the Great Western Railway, a diaphragm, or divisional 4-inch water-space, has been placed across the middle of the fire-box, with the view of obtaining increased heating surface. This diaphragm has its lower edge (in which deposit takes place) made straight, and about 2 in. below the general surface of the fire-bars, but its upper edge is of the form of an inverted arch, in order to promote the free delivery of the steam generated within it into the steam-dome. The sides of the fire-box, where the diaphragm is attached, are not cut away to form passages for the water and steam, but are pierced with a series of circular holes, 3 inches in diameter, to permit a due circulation without uselessly weakening the fire-box; but the uppermost hole of the series must be placed at the highest point of the diaphragm, otherwise an accumulation of steam, and consequent injury at that point, will ensue. The use of a diaphragm is found to be beneficial in the case of a very powerful engine, provided its upper edge be made sufficiently low to admit of the tubes being conveniently drifted over it, and to allow the dart to be used with facility, in dropping the front set of fire-bars.

The ash-box consists of a plate-iron tray, placed below the fire-box, to receive the burning ashes that drop from betwixt the fire-bars. In the earlier locomotives, no ash-boxes being used, the red-hot ashes were dispersed to a considerable distance by coming in contact with the wheels, and conflagrations were often thereby originated. The ash-box should be as large as convenient, and not less than 10 in. deep, otherwise it will materially impede the draught; but if of ample dimensions, and closed at the sides and back, it will increase the draught, particularly when running against a head wind, at which time a strong draught is required. A hanging shutter to open or close the front of the ash-box forms a good damper. The bottom of the ash-box is placed about 9 in. above the level of the rails, and should on no account be nearer than 6 in., otherwise the engine cannot pass safely over stones or similar objects lying accidentally between the rails.

Tubes.—The tubes are generally formed of brass; the ferules by which they are secured are for the most part made of steel at the furnace end, and of malleable iron at the smoke-box end, and the holes in the tube-plates are tapered, so that the tubes bind them together. Great care should be taken in securing the tubes, as any neglect will be productive of much inconvenience. The ferules are found to be very injurious to freedom of draught, particularly in very small tubes; and to overcome this objection, the methods we have mentioned and many others have been tried for fastening the tubes in by rivetting over or screwing into the tube-plates; but hitherto no method, except that of internal tube-rings, has been found to answer in the case of brass tubes; but we think it likely that, with wrought-iron tubes, internal tube-rings will be ultimately abandoned. Stephenson has frequently adopted iron tubes of late, in preference to brass, on the score of their greater cheapness and durability; and in some cases, where unusual attention has been paid to them, and pure water used, they have been found to answer very well. A common internal diameter of tubes is $1\frac{5}{8}$ in. If made very small, the tubes are liable to be choked by pieces of coke, and the sectional area will be inconveniently contracted, while, if made much larger, the heating surface will be unduly diminished. The number of tubes varies considerably in different boilers; in one species of locomotive in extensive use the number is 134, and the pitch $2\frac{1}{4}$ in. Sufficient space is left below the tubes for deposit, that it may not be in contact with the tubes and cause them to be burned: the extreme tube of the widest row is about the diameter of a tube from the boiler shell. In the long-boiler engines of Stephenson, from the volume of water contained in them, considerable time is required to get up the steam, even so much as three and a half hours where the ordinary engines take two hours, and they require great care in firing and feeding to prevent the steam running low.

Smoke-box and Chimney.—The smoke-box door of many engines is hinged at the bottom, and is kept shut by means of handles and catches; but the position of the door when open is in that case inconvenient, as it prevents ready access to the tubes. In some of Stephenson's engines, the smoke-box door is in two leaves, which open like the doors of a house, overlapping at the centre, where they are closed by a bar, and at top and bottom by handles and catches. This door admits of the easy examination of the cylinders and valves. A small door is usually left near the bottom of the smoke-box, by which the accumulated cinders may be removed. The bottom of the smoke-box should not be below the ash-pan, or be much nearer the level of the rails than 18 inches, else the waste-water cocks of the cylinder projecting through it, would be liable to injury from objects lying on the line. The smoke-box is lower in goods engines than in passenger engines, on account of the driving wheels being smaller; and, being coupled with the other wheels, the cylinder has frequently to be inclined to let the moving parts work clear of the front axle.

The chimney must not stand more than 14 feet high above the rails. It is sometimes covered with a bonnet of wire-work to prevent the passage of cinders, but such wire-work checks the draught, and is soon worn away and broken by the projected coke; and a perforated plate is sometimes substituted, which is set across the smoke-box and below the blast. This plate should be hinged, and be in two leaves, for the sake of convenience. The sectional area of the chimney is about $\frac{1}{10}$ of the area of fire-grate. The chimney is usually provided with a damper, similar to the disc throttle valve of an ordinary engine; this is generally hung off the centre, and a hole is made in it for the top of the blast-pipe, which projects through it when it is closed. Another damper has been applied by Messrs. Rennie at the smoke-box end of the tubes, consisting of a sliding plate perforated with holes, which when opposite the ends of the tubes will give a free current, and may be made to close them completely if required. Another kind of damper consists of an arrangement of thin bars similarly disposed to the laths of a Venetian blind; the plates being so hinged, that when placed with their edges to the tube plate, they leave the flow of air through the tubes unimpeded, and when hanging down they close up the tubes, or they partially close the tubes in any intermediate position. By either of these arrangements, the hot air is retained for a longer period in contact with the tubes than if a simple damper were used, as each tube is virtually furnished with a hanging bridge which keeps in the hottest air and lets only the coldest flow out. An inconvenient degree of heat in the smoke-box is also prevented. The smoke-box is usually made of $\frac{1}{4}$ plate; the chimney of $\frac{1}{8}$th plate; the blast-pipe of $\frac{1}{8}$th copper, and the steam-pipe of $\frac{3}{16}$ copper.

Framing.—The subject of outside and inside framing has already been discussed at some length at p. 191.; and the best justification of Messrs. Bury's adoption of the inside framing is, that most of the other engineers are beginning to follow their example. In some engines the side frames consist of oak, with iron plates rivetted on each side. The guard-plates are in these cases of equal length, the frames being curved upwards to pass over the driving axle. Hard cast-iron blocks are rivetted between the guard-plates, to serve as guides for the axle bushes. The side frames are connected across at the ends, and cross-stays are introduced beneath the boiler to stiffen the frames sideways, and prevent the ends of the connecting or eccentric rods from falling down, if they should be broken. The springs are of the ordinary carriage kind with plates, connected at the centre, and allowed to slide on each other at their ends. The upper plate terminates in two eyes, through each of which passes a pin, which also passes through the jaws of a bridle, connected by a double-threaded screw to another bridle, which is jointed to the framing: the centre of the spring rests on the axle-box. Sometimes the springs are placed between the guard-plates and below the framing, which rests upon their extremities. One species of spring which has gained a considerable introduction consists of a number of flat steel plates, with a piece of metal or other substance interposed between them at the centre, leaving the ends standing apart. It would be preferable, we conceive, to make the plates of a common spring of different curves, so that the leaves, though in contact at the centre, would not be in contact at the ends, but would be brought into contact gradually as the strain comes on. A spring would thus be obtained that was suitable for all loads.

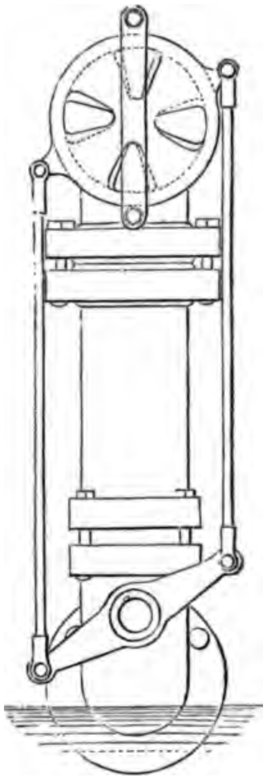
A common mode of connecting the engine and tender, is by means of a rigid bar with an eye at each end, through which pins are passed. Between the engine and tender, however, buffers should always be interposed, as their presence contributes greatly to prevent oscillation and other irregular motions of the engine. A bar is strongly attached to the front of the carriage on each side, and projects perpendicularly downwards to within a short distance of the rail, to clear away stones or other obstructions that might occasion accidents if the engine ran over them. The axles bear only against the tops of the axle-boxes, which are generally of brass; but a plate extends beneath the bearing to prevent sand from being thrown upon it. The upper part of the box in most engines has a reservoir of oil, which is supplied to the journal by two tubes and siphon wicks. Stephenson uses cast-iron axle boxes with brasses, and grease instead of oil, which is fed by the heat of the bearing melting the grease, and causing it to flow down through a hole in the brass. All the engines with outside bearings have inside bearings also; they are supported by longitudinal bars, which serve also in some cases to support the piston guides: these bearings are sometimes made so as not to touch the shaft unless in the event of its breaking.

Steam-dome Pipes and Regulator.—The steam-dome, or separator, from the upper part of which the supply of steam is obtained, is now generally placed over the fire-box; and in Bury's and Stephenson's engines it forms a part of the external shell of the fire-box; whilst in the engines used on the Grand Junction Railway, it consists of an independent cylindrical vessel, attached to the low roof of the fire-box. Either this latter plan or Bury's is perfectly safe and strong, without the addition of stay-rods; but Stephenson's dome presents a large extent of flat surface, from the roof of the internal fire-box up to the arched roof of the external fire-box; and this flat surface requires to be powerfully stayed by angle-irons and tension-rods. We remember an instance in which the accidental omission of one of the numerous tension-rods led to the forcing out and partial explosion of the side of the fire-box, showing how much depends on the circumstance of these rods, with their joints and pins, remaining sound and uninjured from corrosion or other source of injury or decay. In this respect the round fire-box, with its dome, as formed by Bury, has the advantage of superior strength and safety. A large steam-dome is found to be the most efficacious mode yet tried for preventing the evil of priming or damp steam; but no height of dome will entirely prevent it if there be not space enough left above the tubes in the cylindrical part of the boiler to allow the free passage of the steam along to the fire-box and dome, while an excessive height of dome is also found to produce an unsteady motion of the engine, by causing the machine to be top-heavy. A height of about 2 ft. 6 in. above the cylindrical part of the boiler is found to give satisfactory results in practice, and to lead to the production of as pure steam as any greater altitude could secure. In some engines the steam is withdrawn from a dome placed at the smoke-box end of the boiler, into which the steam-pipe rises. It is thought that the ebullition being less violent at this point, the steam will thus be more effectually dried. The steam-pipes are made either of iron or copper, and of these iron best withstands the high temperature of the smoke-box and the impact of the cinders, but it is liable to internal corrosion. The steam-pipe, after entering the smoke-box, divides into two branches, one passing down each side of the smoke-box so as to leave a free space for cleaning the tubes, and also to avoid as much as possible the impact of the hot air and cinders; but in some engines the steam-pipe descends vertically, which is somewhat inconvenient in practice. The area of the steam-pipe is one-sixth to one-eighth of the area of cylinder, and the branch steam-pipes are each about one-tenth of the area of cylinder.

The admission of the steam from the boiler to the cylinders is regulated by a valve or regulator, which is generally placed immediately above the internal fire-box, and is connected with two copper pipes, one conducting steam from the highest point of the dome down to it, and the other conducting the steam that has passed through it along the boiler to the upper part of the smoke-box. Regulators may be divided into two sorts, viz.

those with sliding valves and steam ports, and those with conical valves and seats, of which the latter kind are the best. The former kind have for the most part hitherto consisted of a circular valve and face, with radial apertures, the valve resembling the out-stretched wings of a butterfly, and being made to revolve on its central pivot, by connecting-links between its outer edges or by a central spindle. One of these regulators is shown in *fig.* 325., which makes its mode of operation sufficiently apparent. This species of regulator is easily worked, but is not very accessible, and as the faces are merely projecting rims round the holes, the steam will leak through, and the engine may go on unless the regulator be critically closed. In some of Stephenson's engines with variable expansion gear, the regulator consists of a slide valve covering a port on the top of the valve chests. A rod passes from this valve through the smoke-box below the boiler, and by means of a lever parallel to the starting lever, is brought up to the engineer's reach. Cocks were at first used as regulators, but were given up, as they were found liable to stick fast. A gridiron slide valve has been used by Stephenson, which consists of a perforated square plate moving upon a face with an equal number of holes. This plan of a valve with a small movement gives a large area of opening. In Bury's engines a sort of conical plug is used, which is withdrawn by turning the handle in front of the fire-box; a spiral groove of very large pitch is made in the valve spindle, in which fits a pin fixed to the boiler, and by turning the spindle an end motion is given to it which either shuts or opens the steam-passage according to the direction in which it is turned. The best regulator would probably be a valve of the equilibrium description, such as is used in the Cornish engines.

Fig. 325.

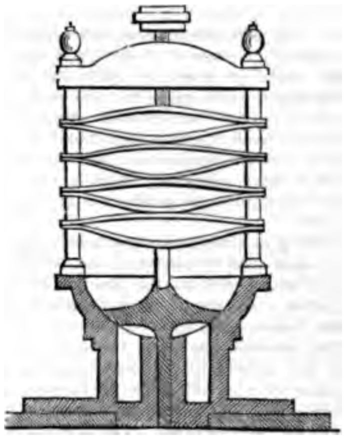


REGULATOR.

Safety Valves and Fusible Plugs. — The safety-valves, as we have observed, are placed upon the dome, in Bury's and Stephenson's engines; but it has been found much better to place them on the cylindrical part of the boiler, as is the arrangement in the engines constructed by Mr. Dewrance for the Liverpool and Manchester Railway, because when an engine commences to prime, the water projected from the blast-pipe generally causes an unusual generation of steam, which escapes at the safety-valve, and in its passage of course accumulates and lifts the surface-water and foam at whatever point of the boiler the safety-valves are situated; thus the farther they are placed from the steam-dome the better, as they will then diminish the evil of priming, which, if placed upon the steam-dome, they would only aggravate. Indeed, if the safety-valves are properly situated, an engineman has the great advantage of being able to check or stop the priming of the boiler on the instant, by causing his safety-valves to blow off strongly. It is requisite to place the safety-valves upon a tubular pillar, of such altitude as to prevent the escaping cloud of steam from obscuring the look-out of the engineman. Bury's 14 in. engine contains a pair of safety-valves of 2¼ in. diameter, exclusive of the mitre; and Stephenson's 15 in. engine contains a pair of 4 in. diameter. The latter dimension is preferable, as large safety-valves are much less liable to adhere to their seats than small ones. Safety-valves require to be tested occasionally; and the best method consists in attaching the valve joint-pin to one end of an ordinary pair of scales, when the over-balancing weight at the reverse end will indicate the real pressure upon the valve, which exceeds the nominal pressure by the weight and friction of the lever, with its joints and spring-balance, and the adhesion of the valve to its seat. To bring this adhesion to a minimum, it is a good plan to make the lip of the valve-seat somewhat flatter than a mitre, that is, at a less angle than 45° with the horizon: 30° answers very well.

The safety-valve is pressed down by means of a lever, as shown at page 198; and a screw at its extremity is attached to a spiral spring balance. To find the pressure per square inch, we have only to multiply the weight indicated on the scale, by the ratio of the two arms of the lever, and divide the product by the number of square inches in the area of the valve; but to save the trouble of calculation, the ratio of the arms of the lever is made so as to be expressed by the number which represents the area of the valve, so that the weight marked on the balance is the pressure per square inch upon the valve. Some allowance must be made for the weight of the valve itself, and part of that of the lever. It is expedient to put a stop upon the screw by which the lever is screwed down or the tension of the spring increased, so as to prevent the pressure from exceeding a safe amount. Lock-up valves, which were intended as a precaution against the recklessness or neglect of the engineer, have fallen into disfavour, as from such valves being inaccessible and seldom being required to act, they became fixed in their seats; but it is an easy thing to make a valve which can be raised, but cannot be forced down by the engineer, and such valves are in general use in steam vessels. In the engines of Cavé, Hick, and Jackson, one of the valves is permanently loaded a little above the usual pressure, and enclosed in a chest; it is usually made with bent, flat, steel springs, pressing against one another, and guided by standards screwed to the valve-seat. One of these valves is shown by *fig.* 326.

Fig. 326.



SAFETY VALVE.

A plug of lead is usually fixed in the furnace crown, which melts if the boiler becomes short of water, and gives notice of the danger. In some engines a cock is attached to the top of the steam-dome, against which a small disc of fusible metal is retained by a ring of brass bolted to the cock, and which is intended as an antidote to explosions. When the cock is opened, the steam has access to the under side of the fusible plate, which when melted is forced through the small hole in the retaining plate; and the engineer being thus warned of the undue pressure, can shut the cock and take measures to reduce the pressure. This, however, is altogether a futile expedient, for the steam would be too much cooled in passing through this cock and small pipe to melt the metal: and even if that defect were remedied, the objections still remain which we stated in page 83., as applying to all fusible plugs, and the danger is increased by leading the engineer to trust to a measure of safety that is inoperative in the hour of danger. Steam gauges have not been applied hitherto to locomotives, on account of the inconvenient height of the column of mercury requisite to balance the steam. But it would be an easy thing to make a steam gauge of moderate dimensions, by making the tube, whether straight or syphon, of glass closed at the top, so that the mercury in its ascent would have to compress the air above it; and the graduations would be equal, or nearly so, if the tube were made taper.

Cylinders and Valves.—The cylinders are made of cast iron, about three-quarters of an inch thick, and should be of hard metal, so as to have but little tendency to wear oval from the weight and friction of the piston. The ends of the cylinder are made about one inch thick, and both ends are very generally made removable. At each end of the cylinder there is generally about half an inch of clearance. The valve is invariably of the three-ported description represented in page 199.: it is made of brass, and is not pressed upon by the valve casing; as it is necessary in the absence of cylinder escape valves that the steam valve should be capable of leaving the face to enable the steam or air shut within the cylinder to escape when the train is carried on by its momentum, and also to afford an escape for the water carried over by the steam when priming takes place. The operation of priming, upon the cylinders and valves is very injurious, as the grit and sediment then carried over with the steam wears the pistons, cylinders, and valve faces very rapidly; so that if the water be sandy and the engine addicted to priming, the pistons and valves may be worn out and the cylinders require re-boring in the course of a few months.

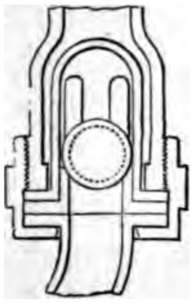
The valve casing is sometimes cast on the cylinder: the face of the cylinder, on which the valve works is raised a little, so that any foreign matters deposited upon it may be pushed off to the less elevated parts by the valve. The area of the steam ports is in some cases one-ninth, and in others one-twelfth or one-thirteenth of the area of the cylinder; and the eduction one-sixth to one-eighth of the area of the cylinder, — proportions which allow at mean speeds of twenty-five to thirty miles per hour, a pressure little different from that of the steam in the steam pipes: for higher speeds the ports should be larger in proportion. The valve casing is covered with a door, which can be removed to inspect the valves or the cylinder face. Some valve casings have covers upon their front end as well as their top, which admits of the valve and valve bridle being more readily removed.

A cock is placed at each end of the cylinder to allow the water to be discharged which accumulates there from priming and condensation. The four cocks of the two cylinders are connected, so that by working a handle the whole are opened or shut at the same time. In Stephenson's engines with variable expansion, there is but one cock, which is on the bottom of the valve chest.

The valve lever is usually longer than the eccentric lever, to increase the travel of the valve. The pins of the eccentric lever wear quickly. Stephenson puts a ferule of brass on these pins, which being loose and acting as a roller, facilitates the throwing in and out of gear, and when worn can easily be replaced; so that there need be no material derangement of the motion of the valve from play in this situation. The starting lever travels between two iron segments, and can be fixed at the dead point or for the forward or backward motions. This is done by a small catch or bell crank jointed to the bottom of the handle at the end of the lever, and coming up by the side of the handle, but pressed out from it by a spring. The smaller arm of this bell crank is jointed to a bolt which shoots into notches made in one of the segments between which the lever moves. By pressing the bell crank against the handle of the lever, the bolt is withdrawn, and the lever may be shifted to any other point; when the spring being released, the bolt flies into the nearest notch.

We have already discussed the subject of locomotive pistons at pages 194. and 195., and can here only add that the pistons which consist of a single ring and tongue piece, or of two single rings set one above the other so as to break joint, are preferable to those which consist of many pieces. In Stephenson's pistons the screws are liable to work slack and the springs to break. The piston-rods are made of steel, the diameter being from one-seventh to one-eighth of the diameter of the cylinder. They are tapered into the piston, and secured there with a cutter. The top of the piston-rod is secured by a cutter into a socket with jaws, through the holes of which a cross-head passes, which is embraced between the jaws by the small end of the connecting rod, while the ends of the cross-head move in guides. Between the piston-rod clutch and the guide blocks, the feed-pump rod joins the cross-head in some engines. The guides are formed of steel plates attached to the framing, between which work the guide blocks, fixed on the ends of the cross-head, and which have flanges bearing against the inner edges of the guides. Steel or brass guides are better than iron ones. Stephenson and Hawthorn attach their guides at one end to a cross-stay, — at the other to lugs upon the cylinder cover; and they are made stronger in the middle than at the ends. Stout guide-rods of steel encircled by stuffing-boxes on the ends of the cross-head would probably be found superior to any other arrangement. The stuffing-boxes might contain conical bushes cut spirally, in addition to the packing; and a ring cut spirally might be sprung upon the rod and fixed in advance of the stuffing-box with lateral play, to wipe the rod before entering the stuffing-box, and prevent it from being scratched by the adhesion of dust.

Fig. 327.



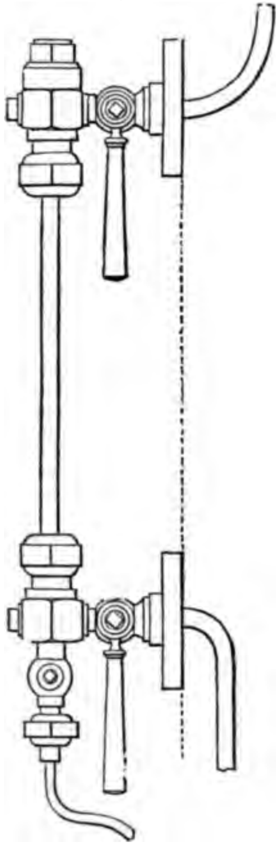
BALL VALVE.

Feed Apparatus. — The feed-pumps are made of brass, but the plungers are sometimes made of iron, and are generally attached to the piston-rod cross-head, though in Stephenson's engines they are worked by rods attached to eyes on the eccentric hoops. There is a ball valve between the pump and the tender, and two usually in the pipe leading from the pump to the boiler, besides a cock close to the boiler, by which the pump may be shut off from the boiler in the case of accident to the valves. The ball valves are guided by four branches which rise vertically and join at top in a hemispherical form, as shown in *fig.* 327. The shocks of the ball against this have in some cases broken it after a week's work, from the top of the cage having been made flat and the branches not having had their junction at top properly filletted. These valve guards are attached in different ways to the pipes; when one occurs at the junction of two pieces of pipe it has a flange, which, along with the flanges of the pipes and that of the valve seat, are held together by a union joint. It is sometimes formed with a thread at the under end, and screwed into the pipe. The balls are cast hollow, to lessen the shock as well as to save metal: in some cases, where the feed-pump plunger has been attached to the cross-head, the piston-rod has been bent by the strain; and that must in all cases occur if the communication between the pump and boiler be closed when the engine is started, and there be no escape valve for the water. Spindle valves have in some cases been used instead of ball valves, but they are more subject to derangement. Slide valves might easily be applied, and would probably be found preferable to either of the other expedients. It would be a material improvement, we conceive, if the feed pumps were to be set in the tender, and worked by means of a small engine, such as that contrived by Messrs. Penn for feeding their tubular boilers. The present action of the feed pumps of locomotives is precarious, as if the valves leak in the slightest degree, the steam or boiling water from the boiler will prevent the pump from drawing. It appears expedient, therefore, that the pumps should be far from the boiler, and should be set among the feed water, so that they will only have to force. If the pump were arranged in the manner we have now recommended, the boiler could still be fed regularly, though the locomotive was standing still; but it would be prudent to have one pump still wrought in the usual way by the engine, in case of derangement of the other, or in case the pump in the tender might freeze. The pipes connecting the tender with the pumps should allow access to the valves and free motion to the engine and tender. This end is attained by the use of ball and socket joints; and, to allow some end play, one piece of the pipe slides within another, like a telescope, and is kept tight by means of a stuffing-box. Any pipe joint between the engine and the tender must be made in this fashion.

The feed-pipe of many engines enters the boiler near the bottom, and about the middle of its length. In Stephenson's the water is let in at the smoke-box end of the boiler, a little below the water level. By this means the heat is more effectually extracted from the escaping smoke; but the arrangement is of questionable applicability to engines of which the steam-dome and steam-pipe are at the smoke-box end, as in that case the entering cold water would condense the steam.

To ascertain the height of water in the boiler, gauge cocks and glass tubes are provided, as in the case of marine boilers. One of these glass gauges is represented in *fig.* 328. The upward turn of pipe proceeding

Fig. 328.



GLASS WATER-GAUGE.

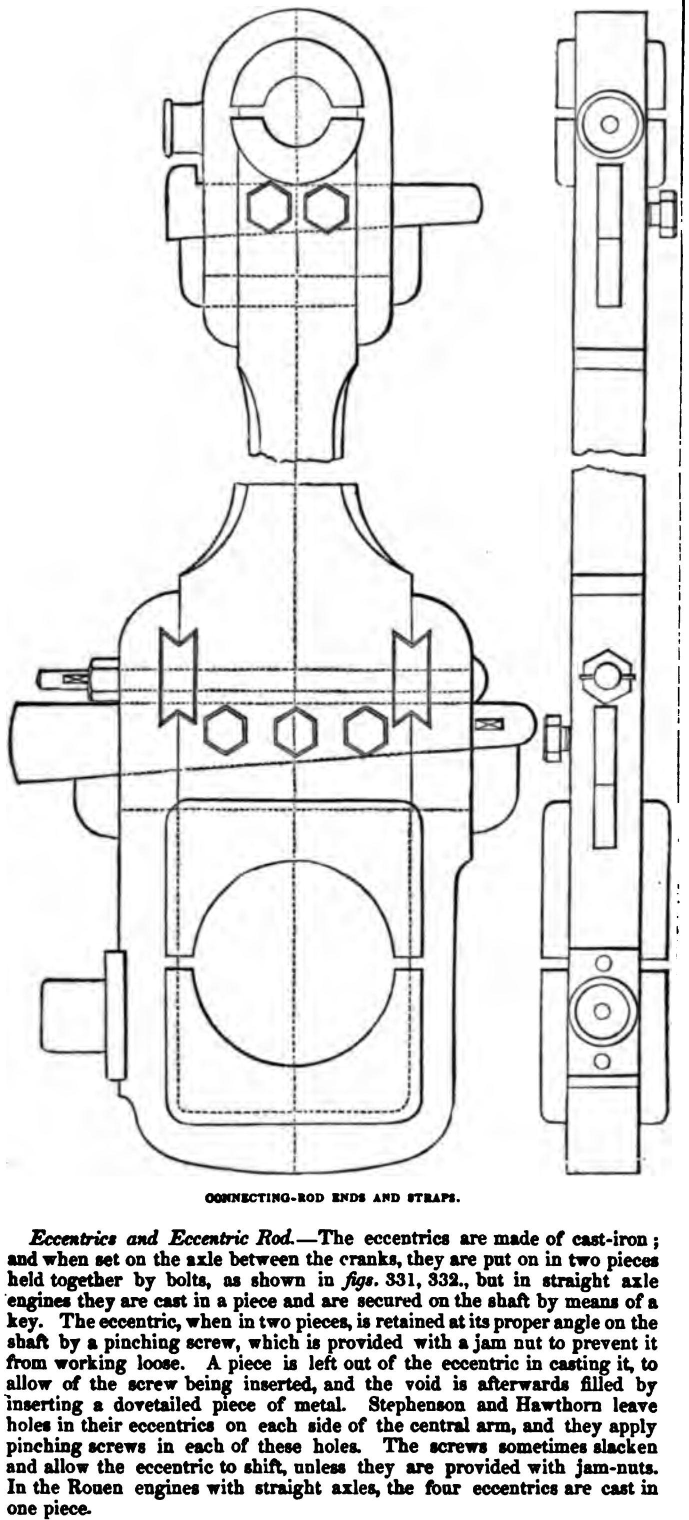
from the top of the tube in the interior of the boiler, is calculated to prevent the water from boiling down through the tube, as it sometimes will do if the boiler be too full. The downward turn of the tube at the lower end does not appear calculated to be of service. A small screw plug is placed on each socket opposite the cock to enable a wire to be introduced, to clear the cock, should it become choked. There are generally three gauge cocks attached to the boiler, — besides the glass tube, — the lowest of which should always run water, and the highest should always blow steam. If the water oscillates inconveniently in the glass tube, the evil may be checked by partially closing the cocks.

Wheels.—The driving wheels are made large to increase the speed : the bearing wheels also are easier on the road when large. In goods engines the driving wheels are smaller than in passenger engines, and are generally coupled together, as in Bury's engine, represented in one of our plates. Wheels are made in various ways; they are very frequently made with cast-iron naves, and with the spokes and rim of wrought iron. The spokes are forged out of flat bars with T formed heads; these are arranged radially in the founder's mould, whilst the cast-iron centre is poured around them; the ends of the T heads are then welded together to constitute the periphery of the wheel or inner tire, and little wedge-form pieces are inserted where there is any deficiency of iron. In some cases the arms are hollow though of wrought iron, the tire of wrought iron, and the nave of cast iron; and the spokes are turned where they are fitted into the nave, and are secured in their sockets by means of cutters. Hawthorn makes his wheels with cast-iron naves, and wrought iron rims and arms, but instead of welding the arms together, he makes palms on their outer end, which are attached by rivets to the rim. These rivets, however, unless very carefully formed, are apt to work loose; and we think it would be an improvement if the palms were to be slightly indented into the rim, in cases in which the palms do not meet one another at the ends. When the rim is turned, it is ready for the tire, which is now often made of steel. The materials for wheel tires are first swaged separately, and then welded together under the heavy hammer at the steel-works, after which they are bent to the circle, welded, and turned to certain gauges. The tire is now heated to redness in a circular furnace; during the time it is getting hot, the iron wheel, previously turned to the right diameter, is bolted down upon a face-plate or surface; the tire expands with the heat, and when at a cherry-red, it is dropped over the wheel, for which it was previously too small, and it is also hastily bolted down to the surface plate; the whole load is quickly immersed by a swing crane into a tank of water about five feet deep, and hauled up and down until nearly cold; the tires are not afterwards tempered. It is not indispensable that the whole tire should be of steel, but a dovetail groove turned out of the tire at the place where it bears most on the rail, and fitted with a band of steel, which may be put in in pieces, is sometimes adopted, though at the risk of being thrown off in working. The steel, after being introduced, is well hammered, which expands it sideways, until it fills the dovetail groove, but it has sometimes come out. The tire is attached to the rim by rivets with countersunk heads, and the wheel is then fixed on its axle. The tire is turned somewhat conical, to facilitate the passage of the engine round curves — the diameter of the outer wheel being virtually increased by the centrifugal force, and that of the inner wheel correspondingly diminished, whereby the curve is passed without the resistance which would otherwise arise from the inequality of the spaces passed over by wheels of the same diameter fixed upon the same axle. The rails, moreover, are not set quite upright, but are slightly inclined inwards, in consequence of which the wheels must either be conical or slightly dished, to bear fairly upon them. One benefit of inclining the rails in this way and coning the tires is that the flange of the wheel is less liable to bear against the side of the rail, and with the same view the flanges of all the wheels are made with large fillets in the corners. Wheels have been tried loose upon the axle, but they have less stability, and are not now much used. Much controversial ingenuity has been expended upon the question of the relative merits of the four and six-wheeled engines; one party maintaining that four-wheeled engines are most unsafe, and the other that six-wheeled engines are unmechanical, and are more likely to occasion accidents. It appears to us that the four-wheeled engines have been charged with faults which do not really attach to them when properly constructed, for it by no means follows that if the axle of a four-wheel engine breaks, or even altogether comes away, that the engine must fall down or run off the line, inasmuch as if properly coupled to the tender, it has the tender to sustain it. It is obvious enough that such a connection may be made between the tender and the engine, that either the hind or the fore axle of the engine may be taken away, and yet the engine will not fall down, but will be kept up by the tender; and the arguments against the four-wheeled engines are nothing more than arguments against the want of such a connection. It is no doubt the fact that locomotive engines are now becoming too heavy to be capable of being borne on four wheels at high speeds without injury to the rails; but we fear the objection of damage to the rail applies to the six-wheeled engine with quite as great force, as the engineer has the power in that case of putting nearly all the weight upon *two* wheels, and if the rails be wet or greasy, there is a great temptation to increase the bite by screwing down the driving wheels upon the rail. A greater strain is thus not only thrown upon the rail than can exist in the case of any equally heavy four-wheeled engine, but the engine is made very unsafe, as a pitching motion will be given to it at high speeds, from being poised upon the central driving-wheels, and the engine will also be more subject to oscillation. Stephenson makes his driving-wheels without flanges, to facilitate the passage of the engine round curves, and if six-wheeled engines be made at all, it appears to be expedient to construct them in that manner. But instead of making enormously heavy six-wheeled engines, it appears to us to be preferable to use four-wheeled engines of moderate weight, and to apply a sufficient number of them to a train to enable it to reach the required velocity. To this there is no doubt the objection, that the expense of the propelling power is greater by this arrangement, as a small engine requires a driver and stoker for itself as well as a large engine. But by making the tender double, with one engine before and another engine behind it, a single driver and a single stoker would suffice for two engines. The starting handles of both engines might be brought to the middle of the tender, so that the engines might be stopped or started simultaneously, and be made to operate in this respect like a single engine. This arrangement appears to us greatly preferable to that of making heavy six-wheeled engines, as the rail will be preserved from the injurious effect of excessive weight, and there will be less loss of power from contracting the blast-pipe when the fire and flue surface is increased by the addition of another engine. In all locomotives, there is a very material loss of power from the contraction of blast-pipe necessary to maintain the blast; at high speeds one half of the power of the engine is lost by the inadequate area of the steam passages of which the greatest loss is that arising from the contraction of the blast-pipe. Tenders are now made larger than heretofore, to obviate the necessity of so many coke and water stations; they should have glass windows all round them, to shield the engine driver from the weather, and enable him during the worst winds and rains to keep a steady look-out. Tenders can be put on any number of wheels, so that inconvenience is not likely to arise from their size and weight.

Cranked Axle. — The cranked axle is made of wrought iron, with two cranks forged upon it, towards the middle of its length, at a distance from each other answerable to the distance between the cylinders; bosses are made on the axle for the wheels to be keyed upon, and there are bearings for the support of the framing. The axle is usually forged in two pieces, which are then welded together. Sometimes the pieces for the cranks are put on separately, but those so made are liable to give way. In engines with outside cylinders the axles are straight, the crank pins being inserted in the naves of the wheels. The bearings to which the connecting-rods are attached are made with very large fillets in the corners, so as to strengthen the axle in that part, and to obviate side play in the connecting-rod. In engines which have been in use for some time, however, there is generally a good deal of end play in the bearings of the axles themselves, and this slackness contributes to make the oscillation of the engine more violent. The bearings of locomotive axles should, it appears to us, be made spheroidal, after the fashion we have already recommended for the paddle-shafts of marine engines, whereby end play becomes impossible; and the momentum of the piston should be balanced by the application of a weight to the wheel. If these precautions be observed, locomotives will not oscillate, whether made with outside or inside cylinders, if only resting on four wheels.

Connecting Rods. — It is very desirable that the length of the connecting-rod should remain invariable, in spite of the wear of the brasses, for there is a danger of the piston striking against the cover of the cylinder, if it be shortened, as the clearance is left as small as possible, in order to economise steam. In some engines the strap encircling the crank pin is fixed immovably to the connecting-rod by dovetailed keys, as shown in *fig.* 330., and a bolt passes through the keys, rod, and strap, to prevent the dovetail keys from working out. The brass is tightened by a gib and cutter, which is kept from working loose by three pinching screws and a cross pin or cutter through the point. The effect of this arrangement is to lengthen the rod, but at the cross-head end of the rod the elongation is neutralized, by making the strap loose, so that in tightening the brass the rod is shortened by an amount equal to its elongation at the crank-pin end. The tightening here is also effected by a gib and cutter, which is kept from working loose by two pinching screws pressing on the side of the cutter. Both journals of the connecting rod are furnished with oil-cups, having a small tube in the centre, with siphon wicks. The connecting rod, represented in *figs.* 329, 330., is a thick flat bar, with its edges rounded. Stephenson's connecting rod is made at the crank end, after the same fashion as the connecting rods of the Black Eagle and Retribution steamers, represented in the plates of those vessels; but instead of a malleable iron cap, a strap of round iron passes over both brasses, and is attached to the T end of the connecting rod by means of nuts upon the ends of the bent iron, which is made thickest in the middle, to resist the strain. This plan has the defect of shortening the connecting rod when the brasses are screwed up, and the brasses require to be very strong and heavy. Hawthorn's connecting rod has a strap at each end, tightened by a gib and cutter; but, to obviate the tendency to shorten the rod, the piston-rod end is furnished with a cutter for tightening the brass outwards. The point of the cutter is screwed, and goes through a lug attached to the gib, and is tightened by a nut. It would be preferable to attach the lug to the cutter and the screw to the gib, as the projection of the screw, when the cutter is far in, would not then be so great. In the engines on the Rouen Railway the piston-rod end of the connecting rod has neither strap nor brass, but simply embraces the cross-head, while the crank end is hollowed out to admit brasses, which are tightened by a gib and cutter. The length of the connecting rod varies from four times the length of the crank to seven times. The long connecting rod has the advantage of diminishing the friction upon the slides.

Fig. 329. *Fig.* 330.

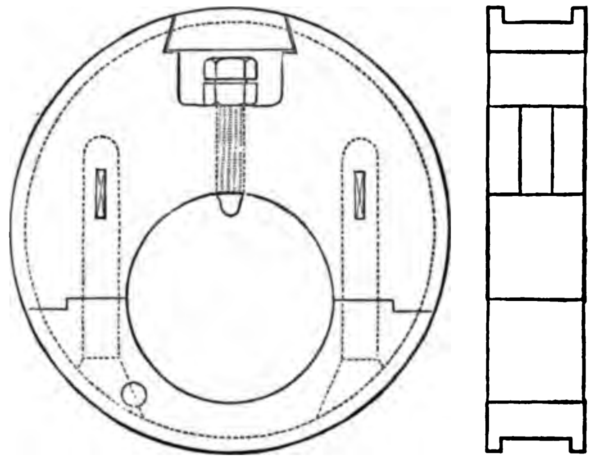


CONNECTING-ROD ENDS AND STRAPS.

Eccentrics and Eccentric Rod.—The eccentrics are made of cast-iron; and when set on the axle between the cranks, they are put on in two pieces held together by bolts, as shown in *figs.* 331, 332., but in straight axle engines they are cast in a piece and are secured on the shaft by means of a key. The eccentric, when in two pieces, is retained at its proper angle on the shaft by a pinching screw, which is provided with a jam nut to prevent it from working loose. A piece is left out of the eccentric in casting it, to allow of the screw being inserted, and the void is afterwards filled by inserting a dovetailed piece of metal. Stephenson and Hawthorn leave holes in their eccentrics on each side of the central arm, and they apply pinching screws in each of these holes. The screws sometimes slacken and allow the eccentric to shift, unless they are provided with jam-nuts. In the Rouen engines with straight axles, the four eccentrics are cast in one piece.

Eccentric straps are best made of wrought iron, as inconvenience arises from the frequent breakage of brass ones. When made of malleable iron, one-half of the strap is forged with the rod, the other half being secured to it by bolts, nuts, and jam-nuts. Pieces of brass are in some cases pinned within the malleable iron hoop, but it appears to be preferable to put brasses within the strap to encircle the eccentric, as in the case of any other bearing. When brass straps are used, the lugs have generally nuts on both sides, so that the length of the eccentric rod may be adjusted; but it is better for the lugs of the hoops to abut against the necks of the screws, and if any adjustment is necessary from the wear of the straps, washers can be interposed. In some engines the adjustment is effected by screwing the valve-rod, and the cross-head through which it passes has a nut on either side of it by which its position upon the valve-rod is determined. The forks of the eccentric rod are steel. The length of the eccentric rod is the distance between the centre of the crank axle and the centre of the valve shaft.

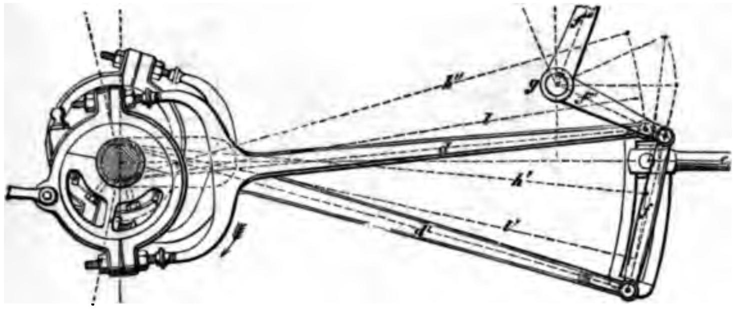
Fig. 331. *Fig.* 332.



ECCENTRIC PULLEY.

Valve motions.—In locomotives the eccentrics are now always fixed upon the axle, and two are used, one for the forward, the other for the backward motion: the loose pulleys have been given up on account of their liability to get out of order from the shocks to which they were subjected by sudden change of direction when worked at a quick speed. The arrangement whereby the motion of the eccentric is transmitted to the valve, is either direct or indirect. In cases of indirect attachment the motion is given through the intervention of levers, and there is some variety in the arrangements by which the reversing is accomplished. Alcard and Buddicome use a pair of eccentrics at the end of the axle, which is straight; the reversing shaft is placed below the level of the piston-rod, and to a lever keyed upon it are attached links of unequal length, connected at their upper extremities with the ends of the eccentric rods, one of which is above and one below the studs on the lever of the valve shaft, so that the upper eccentric rod, being in gear, gives the forward motion, and the lower gives the backward motion. In other engines, forks are situated above and below the stud of the eccentric levers; the forward eccentric rod is lifted up out of gear by a link depending from the lever on the reversing shaft, and by the same movement the backing eccentric is lifted into gear by a longer link connecting it to a lever, not upon the reversing shaft, but upon a shaft below it. Stephenson and Hawthorn have both used a similar arrangement, but admitting of the eccentric rods being both under the studs of the lever on the valve shaft, so that there is no danger, in the event of a disengaged rod falling down, or of any part of the gearing being bent or twisted by both rods being in gear at the same time. The motion of the eccentrics is now frequently transmitted directly to the valves. In Pauwel's arrangement of valve gearing, the valve works on the side of the cylinder, and the valve rod is prolonged in the form of a deep flat blade of a lozenge section, on each side of which a stud is fixed,—one being intended for the notch of the forward eccentric rod, and the other for that of the reversing eccentric. Above them is fixed the reversing shaft, from a lever on which depend two links of unequal length, which are jointed to the ends of the eccentric rods. By working this lever up or down, the eccentric-rods will be alternately engaged and disengaged, and will communicate their respective motions to the valve; or if the lever be kept in its mid position, both eccentrics will be out of gear, and the valve of course will remain stationary. Pauwel's engines are difficult to work, and are subject to shocks from going suddenly into gear: this arises from the whole weight of levers and rods being on the front of the reversing shaft, but the evil might be remedied by attaching a counterbalance to the shaft. Valves situated upon the sides of the cylinders, as in the engine of Stephenson, represented among our plates, are in many cases more easily connected with the eccentric, but they require springs to keep them up to the face, so that it appears preferable to make the faces of the two cylinders inclined to one another rather than upright, if valves on the sides of the cylinders are preferred. Stephenson's link motion is the most elegant, and one of the most eligible modes of connecting the valve with the eccentric yet introduced. The nature of this arrangement will be made plain by a

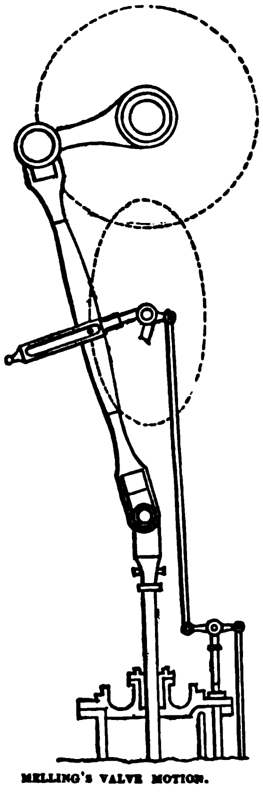
Fig. 333.



STEPHENSON'S LINK MOTION.

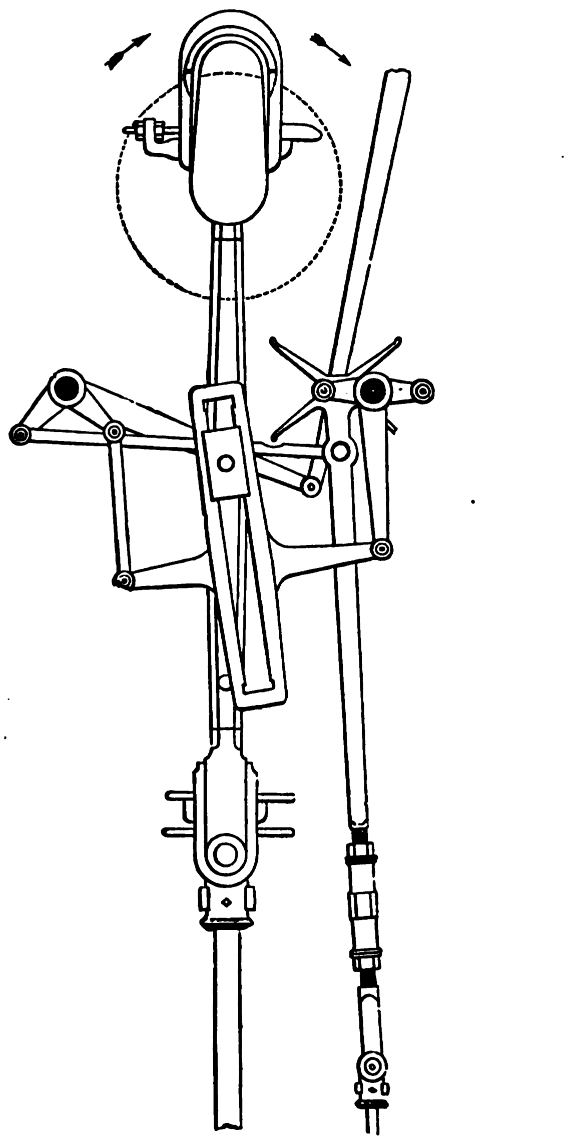
reference to *fig.* 333., where *e* is the valve-rod which is attached by a pin to an open curved link connected at the one end with the driving eccentric-rod *d*, and at the other with the backing eccentric rod *d'*, The link with the eccentric rods is capable of being moved up or down by the rod *f* and bell crank *f''*, situated on the shaft *g*, while the valve-rod remains in the same horizontal plane. It is very clear that each end of the link must acquire the motion of the eccentric rod in connection with it, whatever course the central part of the link may pursue, and the valve-rod will partake most of the motion of the eccentric rod that is nearets to it. When the link is lowered down, the valve-rod will acquire the motion of the upper eccentric rod, which is that proper for going a-head; when raised up, the valve-rod will acquire the motion of the reversing eccentric, while in the central position the valve-rod will have no motion, or almost none. The link motion therefore obviates the necessity of throwing the eccentric rod out of gear; it also enables the engine to be worked to a certain extent expansively, though as a contrivance for working expansively, we cannot hold it as deserving of much commendation. The dead point of the link motion is where the line of the valve-rod bisects the angle formed by the eccentric rods. The maximum forward motion is when the rods are as figured, and the maximum backward motion when the rods *d* and *d'* are in the positions *h''* and *h'*. The best forms of the link motions have side studs, to which the eccentric rods are connected, and these are placed so that at the greatest throw, whether backward or forward, the valve-rod and eccentric rod are in the same straight line, and the valve receives the full throw of the eccentric. A counter-weight is also attached to the shaft to balance the weight of the link and rods. The second eccentric and eccentric rod of the link motion might, it appears to us, be beneficially dispensed with by placing the shaft *g* in the plane of the valve-rod, and attaching a pin to the centre of the link, which would work in the eye of the horizontal arm of the lever *f*. This lever would in such case require to be made much stronger than at present, as it would have to withstand the thrust of the eccentric, and the link would then virtually be a double-ended lever with a moveable centre. Where more convenient, the pin in the centre of the link might be moved in vertical or curved guides, instead of being attached to the lever *f*. The act of raising the link, and with it the eccentric rod, would in effect alter the position of the eccentric on the shaft, and if the eccentric rod were properly proportioned in length, would make the lead right on the reversing side.

Fig. 334.



MELLING'S VALVE MOTION.

Fig. 335.



HAWTHORN'S VALVE MOTION.

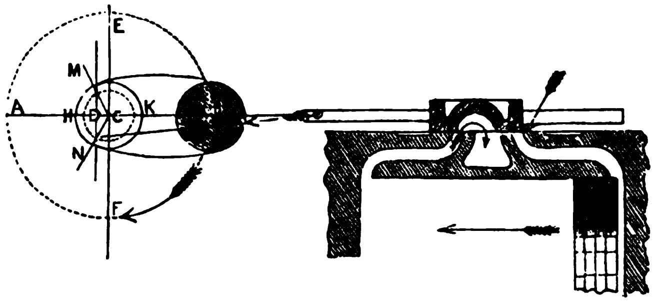
The movement for working the valves is in some cases derived from the connecting-rod, as in the arrangement known as Melling's motion, represented in *fig.* 334., where the valve rod is attached by suitable connections to a pin in the connecting-rod.

A somewhat similar mode of working the valve has been employed by Hawthorn, of Newcastle, which admits of expansive action, and which is represented in *fig.* 335. The pin in the connecting-rod works in a link, to which arms are attached at right angles. The extremity of the lower of these arms is connected by a link and lever to a shaft, which is worked by the reversing handle, while the upper arm is attached to a lever upon the valve-shaft. Upon this shaft there is a double-ended lever, with either end of which a rod, in communication with the valve, gears, according as a forward or reverse motion is wanted. This valve-link is connected by a link with the starting-shaft. The central slot in the link permits the free end movement of the pin on the connecting-rod, while the lateral movement is communicated to the link, and made available for working the valve-levers. To reverse the engine, the inclination of the link must be altered, and the fork in gear must be changed to the other end of the lever, which is done by the same handle: the lead is regulated by the degree of inclination of the parallelogram, which might be changed by lengthening the lever on the reversing-shaft connected with the lower arm of the link, or by shifting it round on the shaft so as to throw the lower arm towards the cylinder. There is much complication in this arrangement; the parts, too, require to be large, and the plan has not been received with much favour, although good results have, we believe, been obtained.

Variable expansive action has recently been extensively introduced in locomotives, and the whole of the various expedients for its accomplishment operate either by altering the travel of the valve, or by the introduction of superposed valves. The first mode is that adopted by Stephenson and Cabrey, and the second is principally used by Mayer and Gonzenbach. In the first the effect is to uncover the steam ports less, and to re-shut them sooner; to hurry the eduction, and to compress the steam shut within the cylinder: from the early closing of the eduction, the advantages due to expansion are partly sacrificed, for the steam escapes before it has done all its work, and power is lost in the compression of vapour. The second class of expansion contrivances is not chargeable with these defects. It admits of the steam being cut off at any part of the stroke, without any derangement of the valve motion, but there is greater complication in the apparatus. In the class with variable throw, the cutting off is the result of a virtual contraction of the ports, which wire-draws the steam, increasing the speed of the entering steam, and making the pressure in the cylinder less than in the passages. In Cabrey's expansion gear, which we have described at page 200., the fault is, that for certain degrees of travel, and when there is much cover on the valve, it may happen that instead of opening the port before the end of the stroke, the valve may not have uncovered the steam port when the piston is about to begin the return stroke. This evil results from the invariable position of the eccentrics on the shaft, and the immobility of the centre of the valve lever. Stephenson gets rid of the defects of Cabrey's system in regard to changing the lead of the eccentric, by rendering moveable the centre of oscillation of the valve lever, as the link may be considered, whereby he virtually turns round the eccentric on the axle. Mayer's gear, which we have figured at page 200., has given very good results, and is free from the defects of Cabrey's and Stephenson's. Whatever be the degree of expansion, it presents the same area of steam port; the eduction is not unduly hurried, the linear lead is unvarying, and the compression of the steam before the piston is but small, and is not liable to increase. The wheel and chain gearing, however, used in working it, are very troublesome, and liable to get out of order, and the valves have a great deal of friction. Gonzenbach's has less friction than Mayer's, and gives equally good results.

How to set the Valves of Locomotives. — When the cylinder is horizontal the crank is horizontal at the ends of the stroke; but it is not vertical when the piston is at the middle of its stroke, owing to the deviation from parallelism introduced from the connecting rod being compelled to move at one of its extremities in a straight line. When the piston is at the end of the bottom stroke, and is gradually advanced towards the middle of the stroke, the end of the connecting rod is carried round by the crank in a curve opposed to that which it would naturally describe round the cross-head as centre; but when the piston has approached the end of the top stroke, the curvature of the path in which the end of the connecting rod is moved by the crank is in the same direction as that of the circle which it would describe round the cross-head, and these curves would coincide if the connecting rod were equal in length to the crank: it will be easily seen, therefore, that at the top stroke the piston rod requires but a small movement to enable the end of the connecting rod to traverse a large portion of the circle of the crank, while at the bottom stroke the piston has to travel farther to allow of an equal arc being described by the crank. From these considerations it follows, that the motion of the crank being nearly uniform, there must be considerable inequalities in the speed of the piston; and more than a half circle will be described by the crank during the top half of the stroke, and less than a half circle in the bottom half of the stroke. The length of the connecting rod is the distance from the cross-head at half stroke to the centre of the shaft; and it is clear, therefore, that at mid-stroke the crank cannot be vertical. The motion of the valve partakes of the same species of irregularity; but as the eccentric rod is much longer in proportion to the radius of the eccentric than the connecting rod, that inequality only may be noted which arises from the relation between the circumference of a circle and its diameter. The irregularity arising from the angle of the connecting rod also affects the valve, but not to an injurious extent in ordinary cases. We need not, therefore, consider the effect of such irregularities in the following directions how to set the valves of locomotives. In *fig.* 336. we have shown the direct connexion, as used in some of Stephenson's locomotives, A E B F representing the crank circle, and the inner circle that of the eccentric. Supposing, now, that the total length of the valve face were equal to the distance between the extreme edges of the steam ports, the valve would be without *lap;* and leaving the question of *lead* out of consideration for the present, that is, supposing that the steam were admitted exactly at the ends of the stroke, the eccentric would be fastened upon the shaft at right angles to the crank; in other words, the small crank which constitutes the eccentric would be at right angles to the large crank, which is attached to the piston-rod. In this way the valve would be in the middle of its stroke when the piston was at either end of its stroke, so as to close both the steam and eduction passages, and to be ready, with the slightest possible advance, to open both for the return stroke of the piston. It has been found advantageous, however, to make the valve face longer than the distance between the extreme edges of the steam ports, so that when it is in the middle of its stroke, it projects or overlaps the ports at both ends; and hence it requires to move through a space equal to the overlap before it is in a condition to open the steam port for the return stroke of the piston. To effect this, it is only necessary to move the eccentric forward in its path, until, at the end of the stroke of the piston, the valve is on the edge of the steam port, ready, as before, upon the slightest farther advance, to admit the steam to the cylinder. Now, as the valve is thus required to move through a part of its travel or throw equal to the overlap at each end, and as the throw is equal to the diameter of the circle which the eccentric describes, it follows that, to give the requisite advance, that distance must be measured upon the diameter of the circle, and the corresponding position of the centre of the eccentric is that of which we are in search.

Fig. 336.



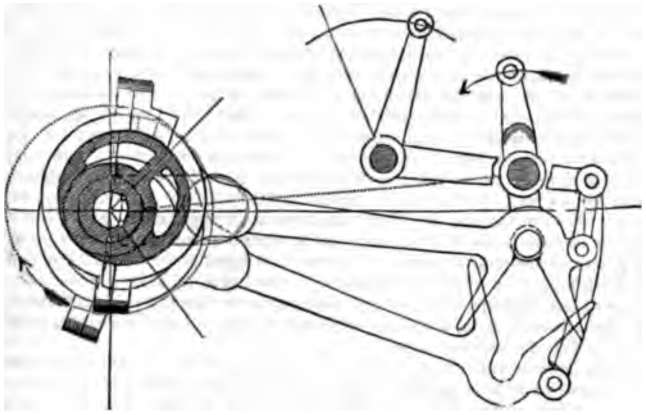
SETTING VALVE WITH DIRECT ATTACHMENT.

On the remote side of the centre of the crank shaft, and on the line of centres, mark off D C, the amount of overlap at each end of the valve, and draw a line parallel to E F, the vertical centre line of the crank shaft; the arc of the eccentric circle intercepted between these parallel lines is that through which the eccentric must move, in order to draw the valve through a portion of its stroke equal to the overlap D C; and the point in which the line intersects the circle of the eccentric is, therefore, the position which the centre of the eccentric should occupy when the piston is at the end of its down-stroke, and on the very point of beginning its up-stroke. In practice, however, the valve is not so set as to open simultaneously with the commencement of the stroke of the piston, but is set so that the steam commences to flow into the cylinder a very little before the beginning of the stroke; and hence, when the piston actually commences its stroke, the valve has already partially opened the port. To make this adjustment an additional advance must be given to the valve, and of course in the same direction; and the amount of *lead*, or opening, which the port has at the commencement of the stroke of the piston, must be added to the *lap*, their sum from C to D being treated the same in every respect as if the whole were *lap*, and so, for the sake of brevity, we may treat it.

Let us suppose now that it was required to find the length that the eccentric rod should be: — Place the crank horizontal, so that it may have the piston at the bottom of its stroke; bring round the eccentric to the corresponding position which we found it should occupy, and measure the distance from that point to the centre of the joint by which the eccentric rod is to be attached to the valve rod; this will be the length of the eccentric rod. When the length of the eccentric rod is known, either the valve or eccentric may be put in its proper place, if one of them be already set: thus, if the valve be set, as in the drawing, and the eccentric rod connected also with the eccentric, it will bring the latter into its place, where it may be fixed; but if the valve could not be conveniently set, it would then be necessary to take the following method, which requires the knowledge of the amount of lap, and the length of the eccentric rod. Find, as before, the position of the eccentric, attach the rod, and the valve must come into connection in the proper position. In practice, the most convenient method of finding the position of the eccentric with a given lap is to draw a circle, such as H K, representing the crank shaft, upon a board or a piece of sheet-iron, and another equal to the circle of the eccentric, and draw two diameters perpendicular to each other; mark off from the centre of the crank shaft, and upon one diameter, the amount of lap C D; through this point draw a line parallel to E F, the other diameter; the points in which this line cuts the circle of the eccentric are the positions of the forward and backward eccentrics. Through these points, and from the centre of the crank shaft, draw lines C M, C N, which will intersect the circumference of the crank shaft; upon this circumference measure with a pair of compasses the chord of the arc intercepted between either point of intersection and that of the vertical diameter E F; and the lines of diameters being first drawn upon the shaft itself, then, by transferring with the compasses the distance found upon the diagram, the proper position of the eccentric at the end of the stroke of the piston is at once determined; and this being marked upon the shaft, the eccentric can at any time be set, by bringing it round to that mark. Before leaving this figure we may remark, that as the valve in Stephenson's locomotives of this kind is on the side of the cylinder, the cylinder face should be towards us in the drawing. As this arrangement, however, would have afforded a less easy explanation we have adopted the present one. It will also be observed that the crank shaft and cylinder are too close, and are not in a line with each other; but this, while it could not be easily avoided, is at the same time of no importance in considering the respective motions of the piston and valve, crank and eccentric, which are shown in their true relative positions. The crank is upon the centre, and the piston, consequently, at the end of the bottom stroke; the eccentric and valve being put in advance of the piston by the lap, have shut off the steam before the end of the stroke, and have also opened the eduction in readiness for the up-stroke; whereas, without lap, the valve would shut off the steam at one end, and open the eduction at the other, simultaneously with the termination of the stroke of the piston.

In *fig.* 337. we have a different kind of valve gearing, there being levers, which reverse the direction of the motion; that is, while the eccentric rod and lever are moving in one direction, the valve rod and lever being on the opposite side of the weigh-bar shaft, are moving in the opposite direction. In the former case there were no levers, and therefore no reversal of the motion. Hence, in order to give the valve the same motion as before, in relation to the crank, it is necessary to throw the eccentric to the opposite side of the crank shaft, so that its motion may be in the reverse direction, to compensate for the reversing action of the levers. For whereas, when upon one side of the shaft they caused the valve to move in the same direction as themselves by means of the eccentric rods, now that the levers are introduced, the eccentrics must themselves move in an opposite direction, to give the valves the same motion as heretofore. And this can only be done by putting the eccentrics on the opposite side of the crank centre, round which they move, and, of course, in an opposite direction.

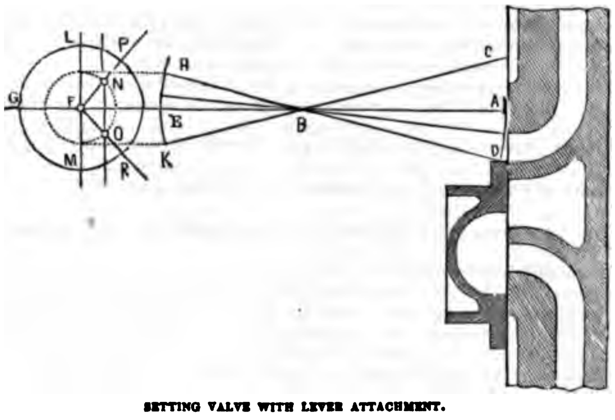
Fig. 337.



INDIRECT ECCENTRIC ATTACHMENT.

Fig. 338. is intended to illustrate the valve connection of the common locomotive, in which the motion of the eccentric is communicated through levers to the valve, and generally with an increase of throw. In this figure we have the cylinder face, with the valve upon it, at one end of its travel. Measure off the length of the valve throw, from the end of the valve face, in the direction of its travel. The throw of the valve may best be found by adding the lap to the breadth of the steam-port, and doubling their sum. If there were no levers intervening between the valve and eccentric, the line thus measured, which is the throw of the valve, would be the diameter also of the circle described by the centre of the eccentric pulley; but the use of levers interferes with this proportion unless the levers be made of equal length. The effect of levers of unequal length, in making a proportional inequality between the throw of the valve and of the eccentric, will be readily seen by reference to a diagram. From the centre A of the diameter, representing the throw of the valve, draw a line perpendicular to the valve face; and from the same point measure off, upon that line, the length of the lever A B, which is to be attached to the valve rod, and which, for distinction, we shall call the valve-lever. From the point B thus found as a centre with the radius B A, describe a portion of a circle intersecting perpendiculars drawn from C and D, the extremities of the line which represents the throw of the valve; from those points in the circumference of the circle produce lines through the centre B. On either side of the centre line A E, and at a distance from it equal to the radius of the eccentric, draw a parallel line. From B as a centre, with the distance from the centre B to the points H K,—in which the parallels intersect the produced lines of the lever, as radius,—describe an arc of a circle; the radius of this circle is the length which the eccentric lever must be, in order to give the requisite throw to the valve. It will be evident from the inspection of this diagram, that if it be desired to give a smaller throw to the valve than that of the eccentric, it is necessary to make the valve lever shorter than the eccentric lever; and if it were desired to make the valve throw greater than the eccentric throw, it is indispensable that the valve lever should be made proportionally longer than the eccentric lever. If, for example, the throw of the valve is to be made twice the throw of the eccentric, then this can only be accomplished by making the valve lever twice the length of the eccentric lever. Hence the relations between these quantities are expressed by simple proportion; and any three being given, we can readily find the remaining one. For the sake of clearness, we shall state the various forms which the proportion will assume.

Fig. 338.



SETTING VALVE WITH LEVER ATTACHMENT.

First.—Given the throw of the valve, the throw of the eccentric, and the length of the lever attached to the valve rod, to find the length of the eccentric lever; we have then the proportion:—

Rule.—*As the throw of the valve is to the throw of the eccentric, so is the length of the valve lever to the length of the eccentric lever.*

If we represent the throw of the valve by T, that of the eccentric by t, the valve lever by L, and the eccentric lever by l, we will have the proportion in a condensed algebraic form thus,—$T : t :: L : l$; or taking the actual dimensions in inches of the engine before us, $4{\cdot}5 : 3 :: 9 : 6$.

Secondly.—Given the throw of the valve, the throw of the eccentric, and the length of the eccentric lever, to find the length of the valve lever. Then

Rule.—*As the throw of the eccentric is to the throw of the valve, so is the length of the eccentric lever to the length of the valve lever;*

Or, algebraically, $t : T :: l : L$; or, as before, in actual dimensions, $3 : 4{\cdot}5 :: 6 : 9$.

Thirdly.—Given the throw of the valve and the lengths of the levers to find the throw of the eccentric.

Rule.—*As the valve lever is to the eccentric lever, so is the valve throw to the eccentric throw;*

Or thus, $L : l :: T : t$; or, $9 : 6 :: 4{\cdot}5 : 3$.

Fourthly.—Given the eccentric lever, the valve lever, and the eccentric throw, to find the valve throw.

Rule.—*As the eccentric lever is to the valve lever, so is the eccentric throw to the valve throw*, or, $l : L :: t : T$, or $6 : 9 :: 3 : 4{\cdot}5$.

We formerly explained how the reversing action of the levers rendered it necessary to set the eccentric on that side of the crank-shaft centre nearest to the cylinder; whereas, in the case of the direct valve connection, it was set on the side remote from the cylinder. Having now found the means of ascertaining the lengths of the levers to be employed with a given throw of valve and eccentric, the next step necessary is to determine the true position of the eccentric upon the shaft, in reference to the crank.

Place the crank-pin in the dead point nearest the cylinder; that is, place the centres of the crank-shaft and crank-pin in a line with the centre line of the piston-rod. Upon this line of centres A G, raise a perpendicular, L M, through the point F. From F draw a circle, the diameter of which is equal to the throw of the eccentric, and another equal to the cranked axle. If the levers are equal, mark off from F, upon the line of centres and on the cylinder side, the amount of lap, and draw a line parallel to L M, cutting the eccentric circle in the points N O. From F draw lines through N and O to the circumference of the cranked axle. The points N and O are the positions of the centres of the eccentric pulleys for the forward and backward gear, only one of which is necessary for going one way. In practice it is convenient to make marks at P R, as the points N and O are inaccessible. If there were no lap upon the valve, there would be nothing to set off from the centre line L M, and therefore that line would give the positions of the eccentrics.

The intersections of the perpendicular A G would give the positions of the eccentrics on the shaft if the connecting rod were infinitely long; but inasmuch as the shortness of the connecting rod introduces irregularity, the true position of the crank at the middle of the stroke of the piston must be taken.

If the lengths of the levers be unequal, as we have already said, the throws of the eccentric and valve will also be unequal; and if the valve lever be the longer, as in the case we have taken, the eccentric throw is less than the valve throw in the same proportion as the eccentric lever is less than the valve lever; and therefore, since the eccentric throw is thus less than the valve throw, by reason of the levers, it follows that the lap, which we set off from F, and which is part of the valve throw, must also be diminished in the same proportion as the whole throw, in order to set off the proper quantity from F. The simplest way of accomplishing this is, by marking off the lap from the line of centres (*fig.* 338.) at the point A, at the same end as we formerly marked off half the valve throw. This distance will be from A to the edge of the port, that being the overlap; then from the edge of the port draw a parallel to A G; and from the point in which this parallel cuts the arc of the longer lever, draw a line through the centre B, and produce it till it cuts the arc K H; the perpendicular from this point to the line E A is the reduced amount of lap, which is to be set off from the point F.

Another useful problem is the method of finding the length of the eccentric rod, the positions of the crank-shaft and the weigh-bar shaft and the length of the eccentric lever being given. From the centre of the weigh-bar shaft, with the length of the eccentric lever as radius, describe an arc; draw a tangent from this to the centre of the crank-shaft; from the centre of the weigh-bar shaft drop a perpendicular to the tangential line; the distance from the point of intersection to the centre of the crank-shaft is the length of the eccentric rod, and the perpendicular is the line of the eccentric lever, when the valve lever is perpendicular to the line of the valve rod: this gives, therefore, the positions in which these levers must be keyed upon the weigh-bar shaft.

In *fig.* 338. we saw that the mid-line of the eccentric rod was the same as the line of the piston rod; but in *fig.* 337. it is thrown down below that of the piston rod, forming an angle with it, the vertex of which is the centre of the crank shaft. In this case the centres of the eccentric pulleys must, consequently, be moved downwards as many degrees as the central line. In order to facilitate this adjustment, we may briefly explain, that every circle is supposed to have its circumference divided into 360 equal parts, called degrees; and if two diameters be drawn in it at right angles to each other, they will divide the circumference into four equal parts, each of which contains 90 degrees. This, therefore, is the means by which the angle is measured; nor will it matter, although the circle be of any size whatever, for it is still equally divided by the two diameters. Hence, if the number of degrees contained in the angle which the mid line of the eccentric rod makes with the line of the piston rod, be measured upon any circle described from the centre of the crank-shaft, and the angle be laid down upon a board, and if from the vertex of the angle a circle be described equal to the diameter of the crank-shaft, the chord of the arc of this circle intercepted between the lines containing the angle, is the distance to be transferred upon the crank-shaft, and through which the eccentric pulley must be moved round, in order to compensate for the obliquity of the eccentric rod. In the example which we have shown in *fig.* 337., the mid-line of the eccentric rod, when in gear, lies at an angle of five degrees with the line of the piston rod; and in all such cases this line is to be taken when reference is made to the valve motion; and the piston-rod line is to be taken when reference is made to the motion of the piston. In the case of *fig.* 338. these lines were made to coincide, for the sake of simplicity. For further information respecting the setting of valves, we refer the reader to pages 89. and 225.

Miscellaneous Remarks respecting Locomotives.—The tractive force requisite for drawing carriages over well-formed and level common roads is about $\frac{1}{30}$ of the load, at low speeds. On railways, the tractive force has generally been rated at about $\frac{1}{300}$ of the load, or 7½ lbs. per ton, at low speeds; but in well formed railways the tractive force is probably less than this, to keep the train moving slowly. The resistance of railway trains, however, increases rapidly with the speed, on account of the resistance of the atmosphere; and the resistance occasioned by the atmosphere may be taken at 15lbs. per ton, with an ordinary passenger train moving at the rate of 30 miles an hour. The friction of the engine and the resistance of the rails vary simply as the velocity, if the power of the engine remains the same; but the resistance of the atmosphere varies as the square of the velocity, and the power requisite for overcoming that resistance as the cube of the velocity: so that by doubling the speed of a train, by diminishing the load without increasing the power, the friction is doubled, the atmospheric resistance is made four times greater than before, and the power requisite to overcome that resistance eight times greater. This shows the extravagance of high speeds, even if the power were as economically produced at high speeds, which is by no means the case. In moderately light trains upwards of 50 per cent. of the power is expended in overcoming atmospheric resistance, in speeds of about 35 miles per hour; and the loss will be greater if the trains be very light, and present a large frontage.

We have already stated, at page 48., that in low-pressure condensing engines the evaporation of one cubic foot of water from the boiler may be taken to represent a horse power. In high pressure engines, working without expansion, the mechanical efficacy of a cubic foot of water raised into steam will be somewhat less, on account of the resistance to the motion of the piston, occasioned by the pressure of the atmosphere; but in locomotive engines, where the working pressure is very high, the resistance due to the pressure of the atmosphere becomes relatively nearly as small as the resistance due to the rare vapour within the condenser of a condensing engine; and it will not, therefore, be a material deviation from the truth if, in locomotive engines, working without priming, we reckon a cubic foot of water evaporated per hour as equivalent to a horse power. An engine evaporating 200 cubic feet of water per hour, and therefore exerting about 200 horses' power, draws about 110 tons, at thirty miles an hour; but if there were no loss from the resistance of the atmosphere, or of the blast-pipe, and no increased friction upon the engine from the increased power requisite for high speeds, the tractive force if taken at 8 lbs. per ton would only require to be 70·4 horses' power for 110 × 8 × 2640, the number of feet travelled per minute at 30 miles an hour, ÷ 33000 = 70·4 horses' power. The friction of the train, however, at 30 miles an hour, including that of an engine of 200 horses' power, cannot be taken at much less than 10 lbs. per ton; for the friction of an engine increases with the power exerted, which determines the pressure upon its moving parts; and the friction of the carriages is also increased at high speeds, in consequence of the draw-bars being attached below the centre of effort of the frontage exposed to the wind, whereby the carriages are pressed down more firmly on the rails. If the traction be taken at 10 lbs. per ton, then the power requisite for propulsion of a train, setting aside the resistance of the atmosphere, will be about 90 horses' power, and the remaining 110 horses' power is absorbed in overcoming the resistance of the atmosphere and of the blast-pipe. If the speed be increased from 30 to 60 miles an hour, about 200 horses' power will be required for overcoming the friction of the train, and 880 horses' power will be required to overcome the atmospheric resistance; making 1,080 horses' power, which will be necessary to propel a train of 110 tons at 60 miles an hour. The evaporation of a locomotive boiler is greatest when the speed is at its maximum, as the blast-pipe then produces its greatest effect; and the power of the engine varies nearly as the rate of evaporation, provided the blast pipe be not unduly contracted. At ordinary railway speeds the power of the boiler is seven or eight times greater than it would be without the blast, though, indeed, such a comparison hardly holds, as without the blast the fire of a locomotive boiler would not draw at all. At a speed of 20 miles an hour, a locomotive boiler boils off from 10 lbs. to 14 lbs. of water per square foot of heating surface, and the rate of evaporation varies nearly as the ∜ of the speed. The evaporative power of various kinds of boilers is given at page 81.

The adhesion of the wheels upon the rails is about one-fifth of the weight when the rails are clean, and either perfectly wet or perfectly dry; but when the rails are half wet or greasy, the adhesion is not more than one-tenth or one-twelfth of the weight. The weight of locomotive engines varies from 15 to 20 tons. A powerful locomotive engine and tender, such as is suitable for high speeds, will weigh about 25 tons. The consumption of power by the locomotive itself is very great at high speeds, chiefly in consequence of the resistance occasioned by the blast pipe to the free escape of the steam. Mr. Stephenson considers that, at ordinary railway speeds, a locomotive engine will absorb as much power as 15 loaded-carriages, weighing 60 tons; so that in a train of 15 carriages, half the power is consumed by the engine. These determinations, however, are all very indefinite, and experiments are yet wanting to show the power produced and consumed by locomotives under different circumstances. Locomotive engines cost from 1,800*l.* to 2,200*l.* each. They run, on an average, about 130 miles a day, at a cost for repairs of about 2½*d.* per mile; and the cost of locomotive power, including repairs, wages, oil, and tallow, and coke, may be taken at 6*d.* per mile, on economically managed railways. This does not include a sinking fund for the renewal of engines which may be worn out, and which may be taken at 10 per cent. on the original cost of the locomotives. On second class railways the expense of locomotives, and workshops, and tools for repairing them, may be set down at 2,000*l.* per mile.

If D be taken as the diameter, and A the area of the cylinder, the proportions observed by many makers of locomotives may be represented as follows:—Blast pipe, $\frac{D}{4\cdot7}$; ports, $\frac{A}{9}$; diameter of crank axle, $\frac{D}{3\cdot25}$; diameter of crank pin, $\frac{D}{2\cdot36}$; diameter of steam pipe, $\frac{D}{2\cdot75}$; or area of steam pipe, $\frac{A}{7\cdot5}$. The dimensions of locomotives may be further illustrated by an enumeration of the chief sizes of a four and of a six-wheeled engine of modern construction, and we shall select for this purpose a four-wheeled engine by Bury and a six-wheeled engine by Gooch, both in use upon the South Western Railway. The sizes belonging to the four-wheeled engine are distinguished by the letter B before them, whilst to those appertaining to the six-wheeled engine the letter G is prefixed:—

Diameter of boiler inside, B. 3 ft. 1½ in., G. 3 ft. 4 in.; length of boiler, B. 8 ft., G. 8 ft.; thickness of plates, B. $\frac{5}{16}$ in., G. $\frac{7}{16}$ in.; number of longitudinal stays in plates, 9 in 6-wheel; number of tubes, No. 14. wire-guage, 86, 4-wheel; and 133, 6-wheel engine; length of tubes, B. 8 ft. 3 in., G. 8 ft. 4 in.; pitch of stays in fire-box, B. 4 in. G. 5½ in.; length of outside fire-box, B. 3 ft. 3½ in., G. 3 ft. 8¼ in.; breadth of outside fire-box, B. 4 ft. 0½ in., G. 4 ft. 2⅞ in.; depth below boiler, B. 1 ft. 8 in., G. 1 ft. 6 in.; height above boiler, B. 1 ft., G. 7 in.; length of inside fire-box, B. 2 ft. 9 in., G. 3 ft.; breadth of inside fire-box, B. 3 ft. 7 in., G. 3 ft. 6½ in.; thickness of copper plates, G. ⅜ in.; thickness of tube plate, B. ½ in., G. ⅝ in.; from bottom of box to top of bars, B. 4 in., G. 6 in.; from bars to crown of box, B. 3 ft. 6 in., G. 4 ft. 2½ in.; length of smoke-box between plates, B. 2 ft. 2 in., G. 2 ft. 2 in.; breadth of smoke-box outside, B. 3 ft. 3 in., G. 4 ft. 1 in.; thickness of plates for smoke-box, B. ¼ in., G. ¼ in.; diameter of chimney inside, B. 1 ft., G. 1 ft. 2 in.; height of chimney from rails, B. 13 ft. 6 in., G. 13 ft. 6 in.; diameter of steam dome inside, B. 1 ft. 3 in., G. 1 ft. 9 in.; height of steam dome inside, B. 1 ft. 4 in., G. 2 ft. 9 in.; diameter of safety-valve, B. 2½ in., G. 3½ in.; diameter of steam pipes inside (No. 14.), B. 3½ in., G. 4 in.; diameter of branch pipes, B. 3 in., G. 3⅜ in.; diameter of top of blast pipe, B. 2½ in., G. 3½ in.; diameter of cylinder, B. 1 ft., G. 1 ft. 1 in.; length of stroke, B. 1 ft. 6 in., G., 1 ft. 6 in.; length of steam ports, B. 6 in., G. 10½ in.; breadth of induction, B. 1¾ in., G. 2¼ in.; breadth of eduction, B. 1 in., G. 1⅛ in.; thickness of bridges, B. 1 in., G. ⅞ in.; lead of valves, B. 1/16 in., G. ⅛ in.; lap of valves, B. ¾ in., G. 1 in.; distance between centre of piston and valve spindle, B. 11⅜ in., G. 1 ft.; thickness of piston, B. 3¾ in., G. 4 in.; diameter of piston rod, B. 1¾ in., G. 2 in.; diameter of valve spindle, B. 1 in., G. 1⅛ in.; diameter of pump ram, B. 1¾ in., G. 2 in.; diameter of clack balls, B. 1¾ in., G. 2 in.; diameter of feed pipes, inside, B. 2 in., G. 2 in.; diameter of driving wheels, B. 5 ft. 6 in., G. 5 ft. 6 in.; diameter of leading wheels, B. 4 ft., G. 4 ft.; diameter of railing wheels, G. 3 ft. 6 in.; diameter of crank axle, B. 5 in., G. 5½ in.; diameter of crank bearing, B. 5 in., G. 5½ in.; diameter of inside bearing, B. 5 in., G. 5½ in.; diameter of outside bearing, G. 3½ in.; diameter of bosses of driving wheels, B. 1 ft. 6 in., G. 1 ft. 9 in.; diameter of bosses of leading wheels, B. 1 ft. 2 in., G. 1 ft. 4 in.; diameter bosses of trailing wheels, G. 1 ft. 2 in.; length of bearing of axles, B. 7 in., G. 7 in.; diameter of axles, B. 4¼ in., G. 3½ in.; diameter of the bosses of axles, B. 7½ in.; thickness of the bosses of axles, B. 6 in.; breadth of outside frame, B. 6 in., G. 5½ in.; length of outside frame, G. 17 ft. 3 in.; depth of outside frame, G. 7½ in.; thickness of outside frame, G. 3½ in.; thickness of frame plates, G. ⅝ in.; thickness of horn plates, B. 1 in., G. ½ in.; length of driving springs, B. 2 ft. 6 in., G. 3 ft.; breadth of driving springs, B. 4 in., G. 4 in.; number of plates in driving springs 16, 4-wheel; and 14, 6-wheel engine; length of leading springs, B. 2 ft. 6 in., G. 3 ft.; breadth of leading springs, B. 4 in. G. 4 in.; number of plates, 13, 4-wheel; and 12, 6-wheel engine; length of trail springs, G. 2 ft. 6 in.; breadth of trail springs, G. 3½ in.; number of plates, 10, 6-wheel engine; diameter of eccentrics, B. 11½ in., G. 1 ft. 0½ in.; breadth of straps for eccentrics, B. 2 in., G. 2¼ in.; throw of eccentrics, B. 3½ in., G. 2 in.; diameter of weigh-bar shafts, B. 2¼ in., G. 2¼ in.; diameter of reversing shafts, B. 1¾ in., G. 2¼ in.; diameter of journals of reversing shafts, B. 1½ in., G. 2¼ in.; length of journals of reversing shafts, B. 2 in., G. 2½ in.; length of valve lever, B. 7⅛ in., G. 8½ in.; length of eccentric lever, B. 7⅛ in., G. 7½ in.; throw of valve, B. 3½ in., G. 4⅛ in.; length of eccentric rods, B. 5 ft. 8½ in., G. 4 ft. 10 in.; diameter of ferules for eccentric rods, B. 2 in., G. 2¼ in.; length of connecting rods, B. 6 ft., G. 4 ft. 7½ in.; length of reversing levers, B. 1 ft. 9 in., G. 1 ft. 6 in.; length of lifting lever, B. 6 in., G. 1 ft. 1 in.; distance between motion bars, B. 6½ in., G. 11 in.; diameter of cross-head bearing, B. 3 in., G. 2¼ in.; diameter of cross-head bearing in slide blocks, B. 1½ in., G. 1¾ in.; length of slide blocks, B. 7 in., G. 7 in.; breadth of slide blocks, B. 2 in., G. 2½ in.; depth of slide blocks between bars, B. 2¼ in., G. 2¼ in.; depth of butt of connecting rods at large ends, B. 6 in., G. 9 in.; depth of butt of connecting rods at small ends, B. 3⅝ in., G. 5 in.; breadth of butt of connecting rod at large ends, B. 2¼ in., G. 2½ in.; breadth of butt of connecting rods at small ends, B. 2 in., G. 2 in.; diameter of connecting rod in centre, B. 2½ in., G. 2½ in.; breadth inside between frame, B. 3 ft. 3¾ in., G. 4 ft.; depth of inside frame, B. 1½ in., G. 9 in.; thickness of inside frame, B. 4¼ in., G. 4½ in.; width of horns for reception of axle box, B. 6½ in., G. 9 in.; depth of axle-boxes outside, G. 8 in.; depth of axle-boxes inside, B. 9 in., G. 8½ in.; distance from centre of crank to fire-box, B. 1 ft. 4¼ in., G. 1 ft. 3½ in.; distance from leading axle to smoke-box, B. 1 ft. 4¼ in., G. 1 ft. 2 in.; distance from crank to leading axle, B. 5 ft. 6 in., G. 5 ft. 11 in.; distance from crank to trailing axle, G. 5 ft. 6 in.

Economy of fuel in locomotives is materially promoted by working expansively; but all attempts at economizing fuel in locomotives should begin with an increase in the area of the fire grate, so that the power of the engine may not suffer so large a diminution by the creation of the necessary draft. It is a monstrous thing that half of the engine power should be dissipated upon the blast-pipe, as in high speeds appears to be the case, and nearly all this power might be saved by enlarging the grate surface and the area of the tubes. It appears to us not improbable that combined boilers with upright tubes, of the kind represented in page 68., will eventually be introduced for the purposes of railway locomotion. Several of these boilers could be combined in a single locomotive, each being furnished with a short funnel for itself, and any amount of grate surface might then be used that is considered desirable. Boilers of this description, it is true, have the disadvantage of being top heavy, but the tubes might be made short, and the depth of coke upon the bars would not require to be nearly as great as at present, so that these upright boilers would not require materially to exceed in height the steam domes of the existing boilers, which rise to a height of 7 feet above the fire bars. In the fire boxes of existing boilers, it may be an improvement in some cases to zigzag the bars, so that their ends shall present the appearance of the letter w, and the bars which are lowest down should be the widest asunder, as they have the greatest depth of coke upon them, and therefore the air will experience the most difficulty in ascending in that situation. There is no saving of heating surface accomplished by the existing construction of locomotive boilers; and all that is gained by the use of the blast, is, a saving in the area of fire grate, which, with a different construction of boiler, might be obtained with a *diminution* in the weight,— looking to the effective power of the engine, — and with a most important saving of fuel. The tubes may be the same in number and area, — but instead of being set at the end of a furnace that requires to be forced excessively, they may be cut into two or more portions, each of which is set over a fire. If the faggot of tubes be cut into 4 lengths, and each length be set over a fire of the same area as the original fire, it is clear that the effective heating surface remains the same, while the area of the tubes is virtually made four times greater, whereby smaller tubes may be employed. The only addition to the weight, is that of the fire grates and of the additional tube-plates, while the resistance occasioned by the blast will be so much diminished, that at high speeds the engine will exert nearly twice the power it exerted before. At present the size of the tubes cannot be diminished to the extent that might be desirable, as the total area would be also diminished, whereby the resistance to the hot air passing through the tubes would be increased, and a stronger blast become necessary. Small tubes also become choked up with the pieces of coke carried into them by the draft, and are rapidly worn internally from the friction of the cinders, and at the ends, especially in the centre of the fire box, from the impact of the flame; but if the fierceness of the draft were moderated the whole of these evils would be cured.

Every locomotive engine should be furnished with efficient expansion apparatus, of some kind or other; as, setting aside the economy of fuel accomplishable by expansion, it is clear expansion acts beneficially by diminishing the weight of the boiler, which may be made smaller at every increase of the efficiency of the steam. When the draft is strong a great loss of effect is caused by opening the furnace door, from the refrigeration due to the large volume of air admitted; and it would be a material improvement if the furnace could be fed by some such mechanism as the revolving grate described at page 53. The use of sediment collectors in locomotive boilers also appears expedient, as, if judiciously applied, they will effectually prevent the formation of scale upon the tubes, and will also operate as an antidote to priming in many cases. Sediment collectors, applicable to land and marine boilers, have been delineated and described at pages 69. 77, 78, 79, and 80. The form of collector best adapted for a locomotive boiler, will depend in a great measure upon the peculiar structure of the boiler; but generally any form will answer which communicates with the water level, and contains water within it in a tranquil state. The V shaped cuts for establishing the communication between the exterior and interior of the vessel, have been found preferable to holes of any other form; for a subsiding particle, so soon as it falls in a slight degree, gets behind the case of the collecting vessel, and cannot afterwards escape.

CHAPTER XII.

MANUFACTURE AND MANAGEMENT.

MANUFACTURE OF ENGINES.

The best situation for an extensive engine factory, intended for the production of marine and locomotive, as well as of land engines, appears to be in a coal and iron district open to the sea, and affording easy means of inland transport, both by railway and canal. Large towns are not eligible situations for such engine works as depend more upon the production of new articles than the repair of old ones; for in large towns the cost of subsistence is greater than in secluded districts, and the wages of the operative must be higher to purchase the same amount of comfort, or else his comforts must be diminished. In rural situations, too, the working population need not be crowded into the narrow compass they are compelled to be content with in large towns: every man may have a separate house, and every house may have a garden; and a guarantee is acquired for the sobriety and good conduct of the working man in the comforts with which he is surrounded. Men are migratory and intemperate because their homes in large towns are such as to be necessarily distasteful to them; and a factory aspiring to have skilful and respectable men, should be prepared to make some sacrifice towards promoting the improvement of their social condition. A rural factory is the best adapted for carrying these views into effect; and, by selecting a coal and iron district, the expense of transporting these materials to the seat of manufacture is saved. The place selected should be open to the sea, so as to enable vessels to be freighted with machinery intended for distant places at a quay alongside the works, and also to enable iron steam vessels to be fitted with their engines without requiring to send either men or materials from the factory. The paddle wheels and the boilers of marine engines cannot be carried by canal without great inconvenience; and it is only by so placing the factory that vessels can come up to its quays, that expense and inconvenience from such sources are to be avoided. A yard for the construction of iron ships again forms a very natural appendage to an engine factory; but such an appendage cannot exist unless the locality chosen be open to the sea.

But although we consider the sea coast of a coal and iron district to be the best situation for an extensive engine factory, we do not conceive that the supreme direction should be located in so secluded a place. London should be the head quarters of the management of English factories, because there the best orders are to be had, and there the improvements of the age concentre. Obscurity is more likely to overtake a provincial engine factory, if it be not well represented in London; and the persons giving orders for engines generally desire to confer with the managers, who must be at hand to make such interviews possible. In London the plans must be fixed and the drawings made, and they can then be sent into the country for execution. This, we believe, is the method pursued by Messrs. Boulton and Watt, whose engines intended for the London market, though manufactured at Soho, near Birmingham, are, we understand, designed by the members of the firm resident in London, whereby Messrs. Boulton and Watt combine the advantages of metropolitan representation with rural manufacture. In such cases it appears expedient to have a small factory upon the spot for repairs: Messrs. Boulton and Watt have a hulk for this purpose, fitted up internally as workshops, and provided with shear legs for moving heavy weights. In the selection of a metropolitan workshop for the accomplishment of repairs, much must, of course, depend upon the extent and precise nature of the trade. If contracts exist for the repair of locomotives, it appears expedient, in the present condition of metropolitan railways, to repair the locomotives of each railway in a workshop on the line; but such would no longer be the case if a suburban railway were to be made, connecting together the different termini. In that case the whole of the repairs should be executed in one factory, and that factory should be so situated as to be available for the repair of steam vessels as well as of railway locomotives. In such a factory it would be desirable to have the addition of a foundry and forge hammer, but, under other circumstances, it would be preferable to dispense with such aids, as too powerful for the occasion.

To make money by the fabrication of engines, it is necessary to manufacture and not to make them; and those persons generally will make the most money who are content to look upon the business as a trade, and not as a profession. A certain type of engine should be adopted and preserved without alteration, until it becomes so antiquated that people will have it no longer. To the production of this form of engine the various tools must be adapted, and tools may be devised to form the several parts with the utmost exactitude and rapidity, and with the smallest possible amount of manual labour. The production of engines under such circumstances will become a manufacture, and will be attended with the same results, both in the cheapness of the process, and the excellence of the product, as in the case of weaving or spinning by steam instead of by hand power. To produce engines cheaply, and of good quality, tools must be employed which are not only of great capabilities, but which are specifically adapted to the end in view; but it would not pay to construct such tools for the production of only a few engines; and as the tools can neither be changed nor discarded without loss, it is necessary to persist in the manufacture of the same description of engine as long as possible, or until the savings from the use of the tools employed have covered their expense.

It is impossible for us to give any general rules for the construction of factories, for much depends upon the kind and extent of business contemplated, and something also upon the situation. It is most important, however, that a factory should be so easily accessible, both by water and by railway, as to obviate heavy expenses for carriage; and it may for the most part be concluded, that a factory is ineligibly situated which requires to spend anything in cartage. In some cases the expense of carriage is so great, as to constitute a considerable per centage upon the capital invested; and, unlike most other errors, the necessity of cartage, from the badness of the situation, is an error that cannot be retrieved. Abundance of water is a good feature; and, in most cases, a promontory or peninsula in a harbour or river will be found to be an eligible locality. — But we fear these directions are of too general a character to be of much utility; and we shall, therefore, give a description of a factory such as would be suitable for the manufacture of land, marine, and locomotive engines, with a yard for the construction of iron ships; and though not suitable for every case, it may serve as a type, to the features of which other factories may be made to conform.

At right angles with the shore, a long wet dock extends into the land, bounded on the left hand with a parallelogram of buildings divided crossways into three squares. In the first of these squares, and facing the shore, the entrance gate is situated; and at the opposite side of the square is the fitting shop for the heavy engines. Adjoining the gate, on each side, are offices and warehouses, and the dwelling of the manager of the works. On the left-hand side of the square is a range of buildings, on the ground floor of which the planing and boring machines, and other heavy tools are set, and in the superior stories are small lathes and finishing workshops. On the other side of the square is a range of buildings, the ground floor of which is devoted to the fitting together of locomotive engines; above this shop the pattern shop, and place for keeping the patterns, are situated. This completes the first square. The second square is larger than the first, and is bounded on the front by the fitting shop, which separates it from the first square, and at the back by the foundry. The sides of this square are occupied by smiths' shops, by body makers' shops for the construction of locomotive carriages and waggons, and by painting shops, in which the carriages are painted, stuffed, and finished. All these buildings are only of one story, are turned with their gables towards the square, and are lighted from the roof. Rails are laid across the square, with turn-tables at suitable intervals, so that any carriage in any one shed may be easily shifted into any other. For the body makers, lathes and circular saws, drilling and mortising machines are provided, so that the only manual labour required is to put the parts together. At the end of the range of smiths' shops, the rolling mill and forge hammers are placed. The smiths' fires are most conveniently blown by a fan-blast. The forge hammers are worked by means of the atmospheric pressure, which also drives the machines in the boiler shed, and appears calculated to supersede, in many cases, the usual modes of giving motion to machines. Behind the foundry the third square is situated, and its chief use is to hold the foundry boxes; the sides of this square are occupied by shops for the brass founder, the copper smith, the maker and mender of loam boards the foundry smith, &c., and a place is also provided for the clay mill. In the centre of the square is a triangle for breaking iron: the back end of the square is left vacant, to facilitate future additions.

Between the wet dock and the side of these squares of building, is a quay, alongside which vessels lie to get in their engines; the end of the fitting shop is turned to this quay. Instead of cranes in the fitting shop, winches travelling on beams, such as are now generally employed by masons, are employed, and these beams extend through the end of the house and across the quay to the dock, so that a piece of machinery may be lifted in the fitting-shop and deposited within the vessel in the dock, without the necessity of any intermediate process. To support the beams carrying the travelling winches outside the house, pillars stand on the edge of the quay, and the portion of the beams which hang over the quay, are securely trussed by means of iron rods. The roof is continued along over the beams, both to give increased strength and to protect the workmen from the wet, when putting engines on board.

On the opposite side of the dock is the boiler shed, and in continuation of it is the building yard. The boiler shed is a very large structure; it contains smiths' shops for preparing the smith work necessary for boilers and iron ships, and is provided with rivetting and punching machines, and other necessary implements. The boiler shed is lighted from the roof, and the boilers are lifted by means of a travelling carriage running on beams near the roof, arranged as in the fitting shop, and similarly projecting over the dock, so as to put boilers on board. The whole of the roofs are made of iron, which are as cheap as timber roofs, and greatly preferable in every way. A railway runs round the dock, and doors open to the wharf from the foundry, carriage shop, and locomotive shop; so that any heavy article, whether engine, boiler, locomotive, railway carriage, or casting, may be set either on board ship, or on a railway, without incurring the trouble and expense of intermediate removal.

In the tools employed in the construction of locomotives, great improvement may be introduced; and in settling the particular plan of locomotive to be adopted, reference must be had to facility of manufacture. The present method of constructing iron ships is rude and primitive. If a form of vessel be fixed upon for which a mathematical expression may be found, a machine may be contrived that will bend the ribs to the right curve and bevel, and also bend the plates to the right shape. The plate with thickened edges, introduced by Mr. Fairbairn, appears to afford the greatest facilities in the manufacture of iron ships; and if machinery be introduced that will form the parts accurately, it will be possible to make large pieces of a ship by means of the rivetting machine; and the only hand labour that will then be requisite, will be that necessary for fastening these pieces together when put into their places. A rivetting machine, however, will probably be invented, that will rivet the parts in their places; and if the frames be accurately punched, and accurately set, the application of such a machine does not appear to be difficult. Two strong rollers might be made to travel up on the frame to which the plate to be rivetted had just been applied, and these rollers, if suitably formed and suitably directed, would suffice to accomplish the rivetting operation. To guide the rollers, a carriage with four wheels, of which the rivetting wheel was one, would have to be applied upon the inside of the frame; upon this carriage a small cylinder would be set, connected with a vacuum pipe by means of a flexible tube, and so soon as the cylinder was put in operation the carriage would mount up on the frame, the wheels of the carriage being armed with projecting spurs to enter the rivet holes, and thus enable it to advance. Such an instrument would not be applicable, either at the extreme bow or the extreme stern, on account of the curves there to be met with; and the bow and stern would either have to be plated by hand, or to be formed separately by the ordinary rivetting machine, and to be then put in their places. For strong vessels with thick plates machine rivetting is especially desirable, as, with the force imparted by hand rivetting, it is difficult to make the rivets fill the holes.

The loose system pursued in some factories, of allowing the inferior foremen or workmen to fix the shape and dimensions of cocks, bolts, and other subordinate parts, is one likely to lead to much confusion, and is not to be commended. Every thing should be drawn in the drawing-office, even the spanners, oil-cups, and gauge-cocks; and for any misfit, the person who has made the drawing should be responsible, provided his dimensions have been followed. It should be the part of the foreman not to design portions of the work, but to see the work properly executed; and no foreman should be permitted to alter or add to a drawing on any account whatever. Should he perceive any mistake or omission, he should come to the drawing-office to have the requisite alteration made, but should not be suffered to make it himself. It is only by a rigorous adherence to this plan that mistakes and confusion are to be avoided, or that an accurate record can be kept of the work which has been done. The practice with the London engineers is to make their working drawings to a scale of 1½ inches to the foot,—representing portions, however, of such parts as the top ends of the side rods, bottom of connecting rod, &c., of which the form cannot readily be found from the measurements of a rule, of the full size. The drawings are fixed upon boards, and varnished so as to preserve them from the effects of grease; and a ledge of wood is nailed round the edges to keep them down, and prevent the drawing from being rubbed when the boards are piled one upon another. Erection drawings should be given to the foreman of the erecting shop, with all the centres marked in their proper places; and the size should be given to which the cylinder is to be *cast*, as well as the size to which it is to be *bored*. Every erector should have a box for holding his hammers, chisels, and files; and every finisher a drawer for holding his tools. Steel straight edges are preferable to wooden ones for most purposes, and the different workshops should be supplied with them. All tools going out of the factory should be weighed, and weighed again when they are brought back. It will generally be found the best economy for factories to make their own gas, and all the workshops should be well lighted, so as to save candles. Flexible tubes, fitted at the ends with heavy candlesticks, will be necessary to supply gas for the erectors.

To make the manufacture of engines profitable, it is necessary to be able to get good orders, and to be able to manufacture cheaply. Orders are most easily got by makers who have a name: yet a name is not in all cases of itself a sufficient attraction, and other allurements must be presented. The ability to give money accommodation will, in many cases, establish a preference, but the chief reliance should be placed upon the activity of the managing head, who, with competent engineering knowledge, should be a thorough man of business, and whose function it should be to agitate unceasingly among the persons likely to require engines made. In fixing the plan of engine, the highest scientific attainments should be put in requisition; but the plan once fixed, the production of engines ceases to be a profession, and is as much a trade as building or weaving, and, to be profitable, must be pursued on the same system. A fastidious taste, or a wavering disposition, are only barriers to commercial success; and those will make most money who, instead of distracting themselves among superlative refinements, will look chiefly to getting the work done. Improvements have their price as well as their recompence, and, to be profitable, they must be introduced at rare intervals, and then only after they have been satisfactorily tested, so that their success is certain. In their designs and their model experiments, engineers may be as revolutionary as they please; but a manufactory should be a conservative institution, and can never be made profitable amid perpetual changes. The form selected should be preserved intact until the accumulation of new improvements is such as to justify and compel the introduction of another combination, which should in its turn be retained until a new crop of improvements has been raised equal in value to the former. Manufacture is thus reconciled with progress; and the alternative is averted of tedious and expensive production, or a gradual lapse into antiquity.

The most important element of prosperity, however, in the conduct of factories that we can discern, is that of making the workmen employed participators in the profits realised, whereby their energies are effectually enlisted, and their ingenuity stimulated to the device of cheaper methods of manufacture. If this innovation be generally carried into effect, strikes will become impossible; and the ingenuity of the workmen, at present a barren field, will spring up into new forms of life and productiveness. The collective inventive genius of the operative classes is a mine of unspeakable wealth, and will at once be rendered available by making it the interest of the workman to plan cheaper methods of manufacture. The *managers* of factories are generally made participators in the profits realised, and the most beneficial results have sprung from the arrangement; but the principle has not been generally extended to the workmen, though recent experiments show that, in their case, it might be applied with equal advantage. M. Leclaire, a house painter in Paris, has for some years made his workmen participators in the profits of his establishment; and, in a pamphlet recently published, he speaks of the system in the highest terms of praise. Lord Wallscourt has long pursued a similar plan in the cultivation of his estates in Ireland, and its operation has been such as to stimulate the supine Irish peasant into active industry, and to shed prosperity and gladness over a district that was formerly the abode of famine and despair. In reply to our inquiries, Lord Wallscourt says, "I have tried the plan for seventeen years, and have found it to answer much beyond my hopes; inasmuch as it completely identifies the workmen with the success of the farm, besides giving me full liberty to travel on the continent, for a year at a time, and upon my return, I have always found that the farm had prospered more than when I was present." Lord Wallscourt's practice is to reckon every workman as the invester of as much capital as will yield, at five per cent. per annum, the sum paid to him in wages. In a factory conducted on this principle, the capital requisite for the erection of the necessary works, and for carrying the business on, would be regarded in the light of a debenture, upon which a sufficient rate of interest to cover the risks would have to be paid, before any profits could be divisible among the workmen; but a certain rate of wages would be secured to the workmen as a minimum, whether there were profits or not. The profits might be divided every year; and, to avoid a partnership transaction, might be distributed as gifts instead of profits, whereby, too, any workman discharged for misconduct would have no further claim upon the establishment. This is the plan pursued both by Lord Wallscourt and M. Leclaire, and we have their testimony to show that it is in every respect satisfactory.

It is clear that the principle of a fair division of profits satisfies every aspiration of industry. Machinery, instead of being the competitor of the working man for subsistence, will, so soon as this great principle gains an effectual introduction, be his assiduous slave. If machinery ploughs, or spins, or toils in the mine, it is for him that it will perform these beneficent labours; and whatever benefit the introduction of machinery brings, he will participate in it in a fair proportion. Every intellectual capacity will be brought into increased exercise; invention will be stimulated, and improved modes of construction will be devised. We own we think that even six hours of work in the day would be enough; for with good machinery, efficient direction, and such activity as must arise when men are made participators in the profits arising from their labours, as much work may be done in six hours as in ten or twelve hours according to the present system.

Such, then, are the chief considerations which suggest themselves to us in connection with the management of factories. The factory should be commodiously situated, and should aim at the production of large quantities of the same kind of work, so that the requisite tools and appliances may be introduced to make the production a manufacture, and the men will only have tasks to perform with which they have long been familiar. So soon as the plan is settled, all considerations of scientific excellence should be dismissed, and the work should be conducted as if the only object to be considered were the production, at the cheapest rate, of certain hundreds of tons of finished castings and polished smith work. Of course quality must not be sacrificed in the aspiration after cheapness; but the quality being fixed, the question is how to produce the articles required at the cheapest rate. We believe that the adoption of the principle of dividing the profits with the workmen, will add to the employer's gains, and diminish his anxieties; while to the workman it will bring such ameliorations as will at once place him in his true position in society. With the termination of the existing system, the strife now subsisting between masters and men must cease, and they will be knit together for the future by an identity of interests, which will gradually grow up into a mutual confidence and regard.

MANAGEMENT OF ENGINES.

We have already, at page 203., given directions for the management of the pumping engine, and as the management of the rotative mill engine is identical with that of the marine engine, we shall restrict our remarks under this head to the subject of marine and locomotive engines. Marine engines require more intelligence for their management than any other description of engine, partly in consequence of their great size and complication, and partly on account of the serious consequences an accident may entail, if the vessel be at the time in a critical situation from stormy weather or adverse winds. On foreign stations, too, the engineer is thrown very much upon his own resources should an accident occur, and the least weighty consequence of his ignorance or neglect will be to damage seriously a very expensive machine. To the management of marine engines, therefore, our present remarks will be chiefly directed, as if this part of the general subject be mastered, the other branches of it will cease to present any difficulty which the most moderate reflection may not surmount.

The first and weightiest duty of the steam-boat engineer is, to see that the boilers are properly cared for. The length of the watch is generally about four hours, and the engineer on watch should be in perpetual attendance on the boiler, to see that the feed is properly maintained. If the boiler be blown off by means of blow-off cocks, the operation should be performed twice in the watch, or once every two hours. The feed should be so set that the water will rise in the course of two hours from a little below the middle to near the top of the glass gauge tube, and in opening the blow-off cocks the water should be allowed to subside from near the top of the glass gauge tube to a little below the centre. This, it is true, is a very indefinite quantity, for the area of the water level varies in different boilers, and the glass tubes are of different lengths; but the engineer will soon discover the exact quantity of blowing off requisite for the particular boilers he works — the rule being to blow off so frequently or so much as to prevent any accumulation of scale within the boiler. We wish here to repeat again that *in every case in which there is an accumulation of scale in the boiler, the fault lies with the engineer*, who is either ignorant of his duty or inattentive to it. The scale should never be thicker than a sheet of paper in the worst parts, with the black iron showing in other places; and the operation of blowing off must be carried so far that this thickness will never be increased. In some boilers the scale in the water spaces is suffered to accumulate until the spaces are completely choked up in some places, and the iron of the flues then gets red hot, and is bellied inwards by the pressure. When this takes place, the only plan to pursue, if the salted parts be not easily accessible from the interior of the boiler, is to cut large manhole doors in the flues, and to quarry out the salt with appropriate instruments. As much may be quarried out every voyage as can readily be accomplished, and the manhole doors may in the meanwhile be closed by means of cross bars and bolts in the usual fashion. As soon as the boilers are clear, these holes may be covered with plates rivetted on, but if the boilers be considerably worn, the manhole doors will last as long as the boilers, and need not be removed.

In boilers furnished with brine pumps, reliance must not be placed upon the pumps always acting well, and once every watch some water must be drawn off from the boiler to be tested by a salt gauge, to see whether it is too salt or not. There is no salt gauge which is received as a standard, but the engineer may easily make one as follows: — Take a glass phial or eau de Cologne bottle, pour into it so much shot that it will nearly sink in sea water, and then cork it tightly. Take any convenient weight of boiling water, say 33 lbs., add thereto 1 lb. of salt, and then put the phial into it turned upside down, so that the shot will rest against the cork; make a mark at the point at which the water stands on the phial; this represents the saltness of sea water. Add then another pound of salt to the water, marking the point on the phial at which the water stands, and repeat the operation until 12 lbs. of salt have been added, at which point the water will have received as much salt as it can dissolve; transfer the marks upon the bottle to a paper scale, which paste on the inside of the bottle in exactly the same position as the original marks. You will then have a salt gauge which will tell the saltness of brine from the point of sea water up to the point of saturation. Reckoning sea water at 1, the water within the boiler should not exceed the saltness represented by 4, at which point the water contains $\frac{4}{33}$ds of salt. This, though a tolerably correct instrument, is obviously a rude one, and it is preferable to have salt gauges properly made by the glass-blower, but graduated by a boiling solution on the principle we have described. A salt gauge is merely a hydrometer, and may be made by any person conversant with the manufacture of those instruments.

The safety of the boilers being assured, the next point the engineer on watch has to look to, is to see that the pressure of the steam is properly maintained. Here almost every thing depends on the fireman. One fireman will keep the steam up with a moderate consumption of coal, while another, with an increased consumption, will not prevent the pressure from declining, and yet it is hard to say wherein lies the difference of manipulation. It is a common fault, however, with lazy or ignorant firemen, to pile up the coal at the mouth of the furnaces, while the bars at the after end are nearly bare, and if there be any holes in the fire, the cold air will rush up through them and greatly diminish the efficacy of the fuel. Opening the furnace door frequently has also a pernicious effect, and should be avoided as much as possible. It is desirable that the bars should have a considerable inclination, to facilitate the descent of the fuel upon them, and thus keep the after end of the bars effectually covered. Bars are to be preferred that are made of malleable iron, as they are more durable than cast iron bars, and may be made thinner, whereby they more effectually distribute the air among the burning fuel. Bars three quarters of an inch thick on the upper edge, tapering to one quarter of an inch thick on the lower edge, seem to answer very well when the bars are of malleable iron. The greater width between the bars at the under than at the upper edge, facilitates the admission of the air, and the descent of the ashes and cinders. Bars are usually set $\frac{3}{8}$ths of an inch asunder, but this width must be diminished if the coal be very small, and can be diminished with impunity when the bars are thin.

If the boiler when tolerably well fired is still short of steam, a few windsails should be set up and their ends directed into the engine room, so as to send into it a larger supply of air; or by setting the foresail the draft may sometimes be increased. In some cases the hatches through the deck into the engine room are too small to admit the necessary supply of air to the furnaces, and they must then be enlarged, or new ones opened. Partially closing the damper will sometimes increase the generation of steam, and in such cases it is expedient to place a sheet iron hanging bridge at the end of the flues, where they enter the chimney. In the case of tubular boilers, however, this cannot be done; but a sliding perforated plate, or Venetian damper, may be so applied to the ends of the tubes, as to retain the hot air for a longer period within them, thereby increasing the efficacy of the fuel. Whatever be the steam producing powers of the boilers, a vacuum should never be suffered to be formed within them, as it is impossible to blow off if there be a vacuum in the boilers, and the gauge cocks, moreover, will in such case cease to afford any indication of the height of the water level. If the pressure of the steam cannot be maintained, that grade of the expansion cam must be used, which will cut off the steam at such a point as will keep the pressure at the right pitch; or if there be no expansion gear, the throttle valve must be so far closed as to keep the steam gauge nearly up to the point answering to the load on the safety valve. Partially closing the throttle valve of an engine, will have nearly the same effect as the use of an expansion valve, if there be any lap on the steam slide; for the steam, though it presses on the piston with the full force at the beginning of the stroke, when the motion of the piston is slow, cannot maintain the pressure on account of the smallness of the opening, when the motion is quickened; the pressure within the cylinder therefore declines, and if, before the motion becomes slow again, as it will do towards the end of the stroke, the steam be shut off by the lap on the slide, an effect will be obtained almost identical with that which would have followed the application of an expansion valve. The action is further illustrated by the indicator diagram, *fig.* 343. page 248, to which it is sufficient to refer. Partially closing the throttle valve checks priming, and opening the throttle valve or the safety valve suddenly has a great tendency to produce it, as has already been mentioned at page 83. When the boiler primes, the speed of the engine is sure to be diminished, in consequence of the large quantity of water the air pump has then to deliver, and it will be expedient in such cases partly to shut off the injection water. When priming begins, engineers generally close the throttle valves, diminish the supply of injection water, and open the furnace doors. If the priming be very strong, so as to cause the water to leave the boilers very quickly, it is necessary to have a few buckets of water at hand to throw in upon the fire the instant the water subsides below the glass tube. It will not do then to set about the drawing of fires, for all the damage may be done before the fires can be drawn, but the engineer must open the furnace doors and throw in a few buckets of water, standing to the one side to escape the backward rush of the steam, which would otherwise scald him. The fires will not be put out by this regimen, but will be so far damped as to prevent them from doing any injury to the boiler, even though it be a tubular one with brass tubes. The same urgent haste is not necessary, if boilers have begun to salt from the stoppage of the blow-off pipes, and there it will do to draw the fires preparatory to pumping out their contents by the deck pump, if they cannot be blown off through the deck pump sea cock into the sea. But in the case of the water being suddenly carried out of the boiler by priming, or of the water having been suffered to subside too far by the neglect of the feed, the best plan is to quench the fires in the way we have described. If from the neglect of the feed, the flues or furnaces have become red hot, on no account must cold water be thrown in by the pump, else the sudden pressure within the boiler thus created will be sure to make the heated places bulge down, and may perhaps burst the boiler. A plate which has bulged down may be set up again by lighting a fire against it, so as to make the plate red hot, and then forcing it up with a screw jack.

One of the greatest dangers that can occur to a boiler, is that of a safety valve jamming or refusing to act. Every boiler ought to have a safety valve of its own, and if this valve should jam, the steam has still a means of escape through the stop valves into the other boilers, the safety valves of which are not likely to be similarly affected; nevertheless cases have occurred in which the safety valves have all been rendered inoperative, and it behoves the engineer to prepare himself for such an emergency. In one of these cases the cone, which is frequently placed in the ball of the waste steam pipe, became loose, and jammed itself into the mouth of the pipe, whereby, though the safety valves were all open, the escape of any of the steam was prevented. The pressure of steam in the boiler increased until it broke some of the boiler stays, and the engineer being unprepared how to act in such a dilemma, the boiler would no doubt have burst, had not the waste steam pipe given way, when the ball was shot to a great height into the air. In this case the pressure would have been immediately relieved by opening the blow through valves of both engines, and at the same time opening the furnace doors to check the production of steam. The existence of a dangerous pressure within the boiler is always shown by the steam gauge, the mercury of which is blown out when the pressure of the steam becomes dangerously high. If both safety and stop valves were to become fixed at the same time, so that the steam could neither gain access to the engine nor escape by the safety valve, the best plan would be to open the blow-off cocks and all the gauge cocks, throw open the furnace doors, and quench and draw all the fires. Such an accident, however, can hardly happen, and we have never known it to occur in practice.

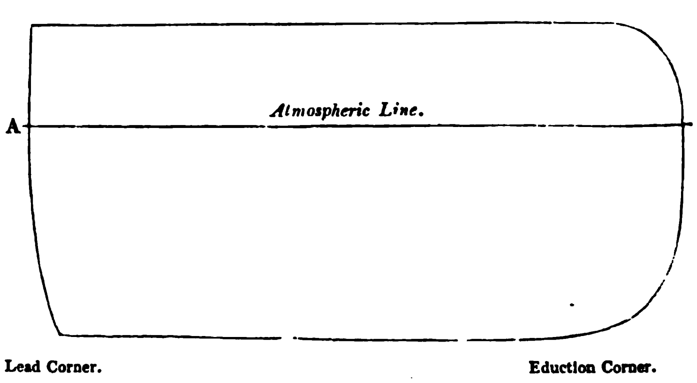
Two or more fires are usually cleaned every watch, depending on the number of the furnaces and the quality of the coal. The fires to be cleaned are suffered to be burned down until there is very little else than clinker left upon the grate, and the whole of this clinker is then raked off, and the fire is lighted afresh. The operation of cleaning the fires is usually performed just before the termination of the watch, and the whole of the ashes are then hoisted up and thrown overboard, the firemen on watch filling the ash-buckets, and the firemen about to come on watch hoisting them up and emptying them into a shoot in the paddle wheel, or over the ship's side. There ought to be a cock on each side of the stoke-hole, about 2 in. diameter, for the admission of water from the sea for quenching the fires and other uses.

Such are the chief points which solicit the engineer's attention in the working of the boilers. In the management of the engines, the first point to be looked to is that the cutters are neither too slack nor too tight, and that none of the brasses are heating. In the generality of engines, the bearing most apt to heat is the crank pin, but much depends on the proportions of the parts, which differ in different engines. It is usual to lubricate the crank pin, when it heats, with sulphur and tallow, which is supplied through a funnel cup instead of the ordinary oil cup, and the same discipline is observed in the case of other bearings. This plan answers well enough when the heating is not considerable, but it will sometimes be necessary to cool the bearing by cold water applied by means of the hose communicating with the deck pump. If the cast iron parts, however, such as the plummer blocks of the main shaft or their covers, become hot, it may crack them to throw cold water upon them suddenly, and in such cases it will be better to begin with hot water from the boiler, shutting off the boiler cock gradually from the pump, and opening the sea cock gradually until cold water is projected upon the bearing. In the malleable iron parts of the engine, cold water may be applied to hot bearings without this precaution, and the best remedy there for a troublesome bearing is the application of the water hose. Bearings, however, rarely heat unless they are too tightly screwed up or the supply of oil to them has been neglected, and they must be slackened and lubricated as well as cooled with water. The heating of a bearing very frequently injures the surface of the metal, and cuts away the brass very much: it should therefore be checked at the outset, and in replenishing the oil cups, which the engineer should periodically do, he ought to feel the bearings to make sure that they are not hot. He should see at the same time that none of the cutters are working loose. A looseness of any of the main bearings will generally manifest its existence by a jerk in the engine, but some of the cutters of the parallel motion may come out and occasion serious breakages without giving any such warning. The same remark applies to any of the main cutters which are not made with a taper, such as the cross-head or cross-tail cutters of some engines, which may come out without giving intimation of the danger. The main cutters about an engine should all be provided with screws, such as is represented in the connecting rod strap in our plate of details, to prevent the cutters from going either back or forward. Generally speaking, cutters have a tendency to work further in, whereby, if the tendency be not counteracted, they will cause the bearings to heat.

The state of the vacuum will be shown by the vacuum gauge attached to the condenser, and if it be imperfect, the cause must be ascertained and the fault corrected. If the hot well be much more than blood warm, more injection water must be admitted, and if the vacuum is still imperfect, there must be some air leak, which the engineer must endeavour to discover. Very often the fault will be found to lie in the valve or cylinder cover, which must then be screwed more firmly down, or in the faucett joint of the eduction pipe, the gland of which will require to be tightened, or the leaking part puttied up. The cylinder and valve stuffing-boxes may at the same time be supplied afresh with tallow, and the door of the condenser examined, if the engine be provided with one. The joints of the parts communicating with the condenser are usually tried with a candle, the vacuum sucking in the flame if the joint be faulty; sometimes the cover of the foot valves leaks air into the condenser, but in side lever engines, this is a very difficult part to examine when the vessel is under weigh.

The power actually exerted by an engine is determined by the indicator, the operation of which we have already explained at page 170., but we may here give a few directions for the use of the young engineer, showing how he may take indicator diagrams himself, and how he may interpret the figures thus obtained. In the case of a steam vessel there is more trouble in applying an indicator than in the case of a land engine, as the proper amount of travel for the string cannot be so easily procured. The most convenient arrangement appears to be to add a small wheel and axle, or wheel and pinion, to the indicator, so that a string attached to the piston-rod and wound on the wheel will give the right motion to the cylinder on which the paper is fixed. The indicator may then be applied to all sorts of engines, whether fixed or oscillating, without involving the trouble of a new method of attachment for each, but the string being tied to the top of the piston-rod, the motion will be reduced at once to that suitable for the paper cylinder, by means of the wheel and axle. It will do, however, when the proposed wheel and axle is not in readiness, to attach the string to any part of the parallel motion, or any part of the side lever which partakes of the motion of the piston. The parallel bar and parallel motion shaft are often selected. If the motion be taken from the side lever, the string must be attached in the central line of the beam, for if attached on the top of the beam near the main centre, the motion may not be the same as that of the piston, and a distorted figure will be obtained. Perplexity is sometimes cast over indicator diagrams in consequence of the improper attachment of the string, and in all cases of apparent anomaly, the first point to be inquired into is the point about the engine, to which the string has been attached. It is a good exercise for engineers to attach the indicator string to parts about the engine which they know to be wrong, in order to familiarise themselves with distorted diagrams, whereby they will be able to detect the imperfection and the causes by which it has been produced.

Fig. 339.



INDICATOR DIAGRAM OF THE CITY OF ABERDEEN.

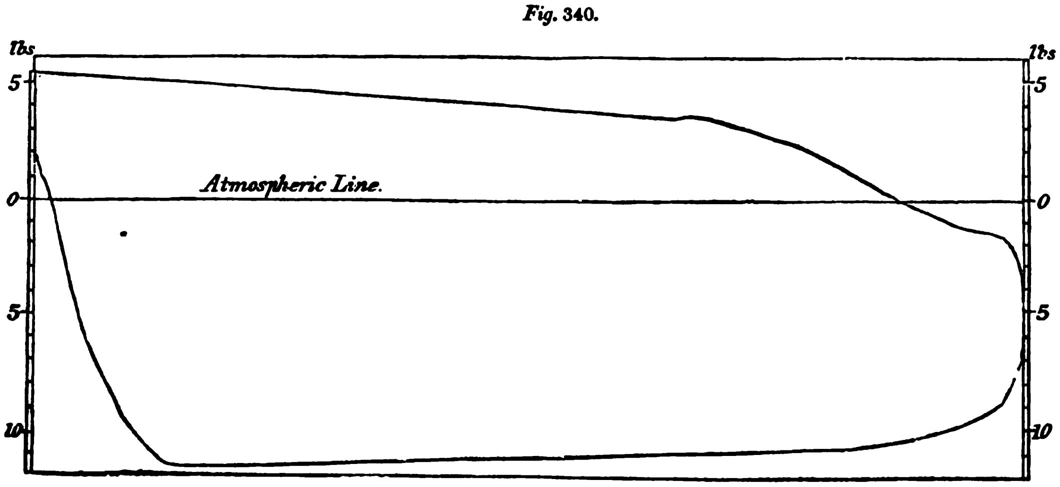
Fig. 339. is a cylinder diagram of the City of Aberdeen steamer. The atmospheric line running through the centre of it shows the point at which the pencil of the indicator stands when there is neither pressure nor vacuum below the indicator piston, and it is traced by suffering the pencil to make a line upon the paper wound round the drum before the cock of the indicator is opened. From the point A, near the left-hand top corner of the figure, the pencil starts on its course, and on the cock being opened, it immediately flies up and forms the upper line of the figure, which represents the pressure of the steam, and for every tenth of an inch—or other distance which in the graduation of the instrument is taken to represent a pound pressure—that the pencil rises, the pressure within the cylinder is that number of pounds above the atmosphere. By the time the paper reaches the extremity of its horizontal travel, the slide valve has shut off the steam and opened the passage to the condenser, when the pencil descends to a position beneath the atmospheric line corresponding to the degree of exhaustion existing within the cylinder. The bottom line of the diagram therefore represents the quality of the vacuum, and by the time the paper has travelled back to the same point from which it set out, the slide valve has closed the eduction passage and again let the steam into the cylinder, when the pencil again springs up to the position due to the pressure of the steam. It is clear from the consideration of this action, that if the steam experienced no obstruction in entering or leaving the cylinder, the figure would be a perfect parallelogram; the pencil would be instantaneously forced up to its highest point, where it would remain until the travel of the paper had terminated, when it would be instantaneously forced down to its lowest point, where it would remain until forced up again by the pressure of the steam. In practice, however, this state of things cannot exist; the steam requires time to enter the cylinder and time to escape from it, and the diagram is more or less rounded at the corners in proportion to the obstruction thus presented. The more square an indicator diagram is at the corners, the more fully is the engine working up to its power with the given pressure of steam. If the corner marked "expansion corner" be cut away very much, the engine is working to a proportionate extent expansively. If the "eduction corner" be much rounded or slanted away, then the eduction passages are too small. If the "lead corner" be much slanted off, then the amount of lead given to the engine is great, or in other words, the steam side of the slide is opened before the end of the stroke. If the "starting corner," or the steam corner, as it might be called, is slanted off, then the steam does not gain admission to the engine sufficiently early. Every change in the engine which occasions a rounding or slanting away of the corners of the diagram, diminishes the power of every stroke; for the space enclosed by the pencil line represents the power of a stroke of the engine, and the area of that space is diminished by every rounding away of the corners. It does not follow, however, that the peculiarities of structure which give a diagram cut away at the corners are necessarily pernicious in all cases. Expansion produces the effect referred to; yet it is known to be beneficial, from the diminished power of the engine being more than compensated by the saving in steam. It is found advantageous to the working of the engine to give some lead to the valve, so that the cutting away of the lead corner of the diagram to a moderate extent is not to be looked upon as a defect; but the eduction corner should be as square as possible, and any rounding of the steam or starting corner is a defect arising from want of lead, or rather from lead on the wrong side,—the steam valve not opening until some part of the stroke has been performed. To compute the power of an engine from the indicator diagram, divide the diagram in the direction of its length into any convenient number of equal parts by lines drawn at right angles with the atmospheric line; set down the lengths of the spaces formed by these lines in measurements of a scale accompanying the indicator, and on which a tenth of an inch usually represents a pound of pressure; add up the total lengths of all the spaces, and divide by the number of spaces; which will give the mean length, or what is the same thing, the mean pressure upon the piston in pounds per square inch. Multiply the number of square inches of area in the piston by the number of pounds on the square inch, and by the speed of the piston in feet per minute, and divide by 33,000, which gives the actual number of horses' power: or we may square the diameter of the cylinder, multiply by the effective pressure per square inch, and by the motion of the piston in feet per minute, and divide the product by 42,017, which gives the same result.

A horse-power is represented by a load of 33,000 lbs., raised one foot high in the minute, which is equal to 528 cubic feet of water raised through the same distance. Mr. Watt, when he first applied his engines to perform work that had previously been performed by horses, felt that some such unit as a horse-power would be convenient in enabling him to estimate the size of engine required. He therefore made experiments to ascertain the weight that might be lifted per minute by the strongest London horses, and found it on the average to be 33,000 lbs. raised through one foot in the minute. It is only the strongest horses, however, that can lift so much; and Mr. Smeaton had previously found that 22,000 lbs. raised one foot high in the minute is as good a performance as can be had from horses of average strength working eight hours a day. Mr. Watt, however, appears to have been desirous that his engines should exceed rather than fall short of their nominal power, and therefore fixed upon a larger performance. In modern engines, the mechanical efficacy of the dimension of engine answering to a horse-power has been greatly increased, so that every horse-power of an engine rated at 100 horses, that is, every nominal horse-power, may lift 66,000 pounds one foot high in the minute, instead of 33,000. A nominal horse-power, therefore, is now merely a commercial unit by which engines are bought or described; but the dimension of engine answerable to this nominal power, is that represented by the actual power in Watt's original engines. A table of these dimensions is given at p. 214., and the result is expressed with tolerable nearness by our rule, p. 107., and by the rule $\frac{d^2v}{6000} = \text{H. P.}$ $\frac{(d-1)^2v}{5640}$ is another rule which gives tolerably accurate results, and which, expressed in words, is,—Subtract 1 from the diameter of the cylinder in inches, and square the remainder, which multiply by the velocity of the piston in feet per minute, and divide by 5640: the result is the horse-power. The speeds of piston, with different lengths of stroke, are given at p. 214. This rule gives 0 for the power of an engine with a cylinder 1 inch in diameter, the whole of the power of such an engine being considered to be absorbed by friction, which is relatively greater in small engines.

Fig. 340. represents an indicator diagram taken from H.M.S. Spiteful, made with a different indicator, in which the graduation is more nearly one-eighth than one-tenth of an inch to the pound of pressure. The scale is shown at each end of the diagram. In this case, the pencil, starting from the atmospheric line, immediately rises up to 5 lbs. pressure; but from the beginning of the stroke the pressure slowly declines, showing that the steam is wire-drawn, and at about three-fourths of the stroke the pressure declines more rapidly, showing that at that point the steam is cut off, leaving the rest of the stroke to be performed by expansion. Before the stroke is completed, the pressure in the cylinder has fallen to between 2 and 3 lbs. below the pressure of the atmosphere. The slanting away at the eduction corner shows that the eduction passages are of insufficient area, and the lead corner shows that there is more lead given to the valve than is usual. The following are some of the dimensions of this engine:—Diameter of cylinder, 63 in.; length of stroke, 6 ft.; stroke of valve, 15⅜ in.; cover on steam side, 3⅜ in.; cover on exhausting side, 1¼ in.; size of ports, 25¾ by 6⅜ in.; load on safety valve, 6 lbs. per square inch. By computing, according to the rules given at p. 90., the amount of expansion due to the amount of lap and stroke of valve here given, it will be found that the steam will be cut off when from one-third to one-fourth of the stroke remains to be completed, which the diagram shows to be the case.

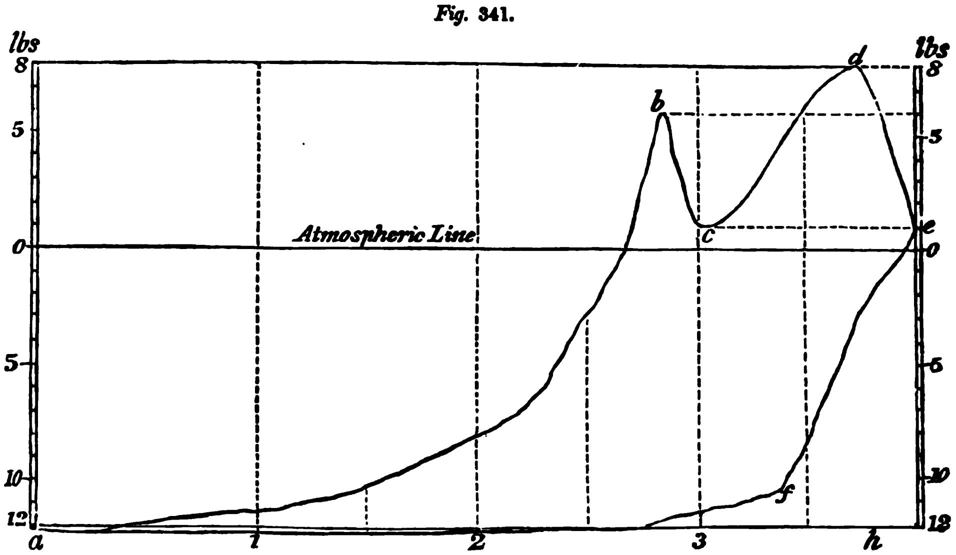
Fig. 341. is an indicator diagram taken from the air pump of the same vessel, the Spiteful, the diameter of which is 3 ft. 1½ in., and the stroke 3 ft. 3½ in. The diameter of the waste water pipe is 12½ in. When the air pump bucket was at the bottom of its stroke, the indicator pencil was at *a*, showing a vacuum in the pump of about 12 lbs. on the square inch. As the bucket rose, the air and vapour in the pump was compressed till the pencil reached the point *b*, showing a pressure of about 6 lbs. above the atmosphere. At this point the delivery valve seems to have opened, and allowed the pent up vapours to escape, when the pencil fell to the point *c*, but here the water in the pump seems to have come against the cover, forcing up the pencil to its highest point, *d*, which shows a pressure of about 8 lbs. above the atmosphere. From this point the pressure appears to diminish to *e*, during the ascent of the bucket, and from *e* to *f* during the downward stroke. The diagram, however, from *d* downwards to *f*, is anomalous, for how can the pres-

Fig. 340.



INDICATOR DIAGRAM FROM CYLINDER OF H. M. S. SPITEFUL.

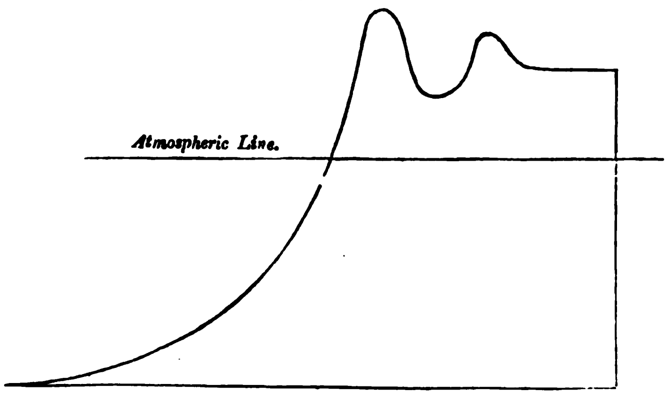
Fig. 341.



INDICATOR DIAGRAM TAKEN FROM THE AIR PUMP OF H.M.S. SPITEFUL.

sure be supposed to descend from *d* to *e* when the bucket is still ascending, and wherefore does the line slant away from *e* to *f*, when it ought to fall perpendicularly, in consequence of the immediate formation of a vacuum in the pump, caused by the descent of the bucket? It appears to us that the cover of the air pump must have leaked air at the time this diagram was taken, and we think further that the string leading to the indicator must have come against some part of the engine towards the end of the top stroke, thereby shortening the string, and quickening at that point the travel of the paper, whereby the slanting off, proper to the recoil of the spring from *d* to *e*, and to the imperfect vacuum from *e* to *f*, would be exaggerated. *Fig.* 342. is another indicator diagram, taken from an air pump, which in this case is that of the City of Aberdeen; and here, it will be seen, there is no distortion such as that which occurs in the Spiteful's diagram. The following are some of the dimensions of the parts of the City of Aberdeen's engines which have reference to the diagrams we have given. Diameter of cylinder, 62 in.; length of stroke, 5 ft. 6 in.; lap on steam side of valve, 1½ in.; pressure of steam, 7 lbs.; lead, ½ in.; diameter of air pump, 37 in.; length of stroke of air pump, 3 ft.; diameter of waste water pipe, 12 in.; height of mouth of discharge pipe above delivery valve, 7 ft. 8 in. The pressure on the air pump bucket due to this head of water is about 4 lbs. on the sq. in. The scale of the diagram is $\frac{1}{10}$th of an inch to the pound pressure, and the pressure shown by the diagram is about 5½ lbs. on the inch; so that about 1½ lbs. on the inch is required to open the delivery valve, and overcome the friction of the passages. The vacuum in the pump is about 12½ lbs. on the inch. The pencil in indicator diagrams very generally makes a few oscillations up and down before it indicates the true pressure. This is caused by the momentum of the indicator piston; and it is therefore expedient to make it as light as possible.

Fig. 342.



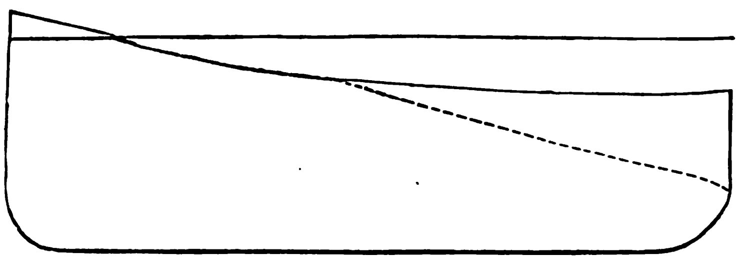
INDICATOR DIAGRAM TAKEN FROM THE AIR PUMP OF THE STEAM VESSEL CITY OF ABERDEEN.

We may here, by way of example, compute the power required to work the air pump of the Spiteful, taking the diagram to represent the power actually expended. We may first divide the diagram by the dotted lines, 1,2, and 3, into four equal parts, which parts we may again subdivide, making eight ordinates altogether. The pressure per square inch on the bucket will therefore be,—during the first eighth of the stroke, 0; during the second eighth, ½; third 1; fourth, 2; fifth, 6; sixth, 13; seventh, 15½; eighth, 18; the mean of which is 7. From this has to be deducted the pressure which assists the bucket in its descent, whether from the leakage of air or otherwise, and which is, during the first eighth, 8½; during the second eighth, 1½; and during the remainder of the stroke, 0. This gives a mean of 1·25 lbs., which, deducted from 7, leaves 5·75 lbs. on the square inch. The weight of water lifted by each stroke, taking the delivery valve to open at the point *c*, will be 395 lbs., which, divided by 1104, the square inches of area of the bucket, gives ·357 lbs. of pressure per square inch, produced by the water lifted each stroke, making 6·107 lbs. effective pressure per square inch opposing the ascent of the bucket. This is equivalent to 3·053 lbs. resisting the motion both ways, or since the air pump is about ⅕th of the capacity of the cylinder, it is equivalent to a fifth of 3·053 lbs. or ·611 lbs. per square inch acting on the piston. Hence the number of horses' power expended in working the air pump of this engine is found by multiplying the area of the piston in square inches by ·611 lbs., then multiplying by the speed of the piston in feet, and dividing by 33,000.

In marine engines the air pump is always made of a larger size than that commonly used for land engines; for when the speed of the engine is momentarily diminished by the waves rising around the paddle-wheels, the injection water is all the while running into the condenser in undiminished quantity, and unless the air pump be very large, it will be unable at such times to deliver the water.

Fig. 343. is an indicator diagram taken from the cylinder of a land engine 54 in. diameter, and 5 ft. 6 in. stroke, erected by Mr. Fairbairn. The steam in the boiler is of a pressure of 3½ lbs. on the square inch, which pressure is not reached in the cylinder, and there therefore appears to be condensation in the steam pipes. The pressure is tolerably well maintained at the commencement of the stroke, on account of the slowness of the motion at that time; it rapidly declines as the speed of the piston quickens, but rises somewhat towards the end of the stroke, in consequence of the diminution of the piston's speed. If the valve had been furnished with sufficent lap to cut off the steam at half stroke, the diagram would have followed the direction of the dotted line, and the effect would have been superior. The engine is obviously working much below its power.

Fig. 343.



INDICATOR DIAGRAM OF A LAND ENGINE THROTTLED BY THE ACTION OF THE GOVERNOR.

The attendants upon engines should prepare themselves for any casualty that may arise, by considering possible cases of derangement, and deciding in what way they would act should certain accidents occur. The course to be pursued must have reference to particular engines, and no general rules can therefore be given; but every marine engineer should be prepared with the measures to be pursued in the emergencies in which he may be called upon to act, and where every thing may depend upon his energy and decision. If the ship springs a leak, the water may generally be kept under by injecting from the bilge, and every steam-vessel should be provided with cocks for this purpose. These cocks should not communicate with any rose within the condenser, as the water drawn from the bilge is not clean water, and a rose within the condenser would probably soon become choked up. Should there be no injection from the bilge, a great deal of water may be lifted out by partly opening the snifting valves, but should they be of such a construction as not to admit of being opened by a handle, or should they be in an inacessible position, the cover of the foot valve, or the man-hole door of the condenser, may be slackened. If the snifting valve cannot be opened readily, the injection may be shut off, so that the engine will heat and vitiate the vacuum, and the valve will then open of its own accord during the descent of the air pump bucket. When raised, it must be prevented from closing again by something being wedged in below it: the steam will then be condensed in the air pump, and the water drawn through the snifting valve will, in all ordinary leaks, soon leave the ship dry. If fire break out in the vessel, the best plan is to keep all the hatches close, to scuttle the deck, and to direct the hose leading from the deck pump upon the fire. The fire hose must on no account be used for pumping out the boilers, washing the decks, or other such purposes, but must be kept in a locker close beside the deck pump, for the single purpose of quenching fire; and should be examined and oiled once a month. Cotton waste, if oil be spilled upon it, is liable to spontaneous combustion, especially if kept in a hot place; and such combustibles should never be kept in lockers behind or near the boilers, or in any place where there is much light wood work that would readily take fire. The coals often catch fire from spontaneous combustion, but damage rarely arises therefrom: they should be quenched immediately the fire is discovered, by directing upon them a stream of water from the hose. Coal or combustibles of any kind should not be kept under the cabins, as it would be almost impossible to put out a fire among the light joiner-work of the cabins. Some vessels are fitted with a steam-cock for quenching fires, by filling the place with steam; but such a cock, being seldom used, is likely to be neglected and become so much corroded, that it cannot be turned when wanted. If collision occur, and the steamer is cut down by another vessel to the water's edge, it may be necessary to blow off one wing boiler instantly, and fill up the other, so as to give the vessel a list to raise the broken part out of the water. There is no time for hesitation in such cases: the engineer must decide on the instant what he is to do, and must do it at once. In some cases of collision, the funnel is carried away and lost overboard, and such cases are among the most difficult for which a remedy can be sought. If flame come out of the chimney when the funnel is knocked away, so as to incur the risk of setting the ship on fire, the uptake of the boiler must be covered over with an iron plate, or be sufficiently covered to prevent such injury. A temporary chimney must then be made of such materials as are on board the ship. If there are bricks and clay or lime on board, a chimney may be built with them, or if there be sheet-iron plates on board, a square chimney may be constructed of them. In the absence of such materials, the awning stancheons may be set up round the chimney, and chain rove in through among them in the manner of wicker-work, so as to make an iron wicker chimney, which may then be plastered outside with wet ashes, mixed with clay, flour, or any other material that will give the ashes cohesion. War steamers should carry short spare funnels, which may easily be set up should the original funnel be shot away; and if a jet of steam be let into the chimney, a very short and small funnel will suffice for the purpose of draught.

If the crank pin breaks, the other engine must be worked with the one wheel. It will sometimes happen, when there is much lead upon the slide valve, that the single engine on being started cannot be got to turn the centre if there be a strong opposing wind and sea;—the piston going up to near the end of the stroke and then coming down again, without the crank being able to turn the centre. In such cases it will be necessary to turn the vessel's head sufficiently from the wind to enable some sail to be set, and if once there is weigh got upon the vessel, the engine will begin to work properly, and will continue to do so, though the vessel be put head to wind as before. If the eccentric catches or hoops break or come off, and the damage cannot readily be repaired, the valve may be worked by attaching the end of the starting handle to any convenient part of the other engine, or to some part in connection with the connecting rod of the same engine. In side lever engines, with the starting bar hanging from the top of the diagonal stay, as is a very common arrangement, the valve might be wrought by leading a rope from the side lever of the other engine through blocks, so as to give a horizontal pull to the hanging starting bar, and the bar could be brought back by a weight. Another plan would be to lash a piece of wood to the cross tail butt of the damaged engine, so as to obtain a sufficient throw for working the valve, and then to lead a piece of wood or iron from a suitable point in the piece of wood attached to the cross tail to the starting handle, whereby the valve will receive its proper motion. If the shafts or cranks crack, the engine may nevertheless be worked with moderate pressure to bring the vessel into port; but if the crack be very bad, it will be expedient to fit strong blocks of wood under the ends of the side levers, or other suitable part, to prevent the cylinder bottom or cover from being knocked out, should the damaged part give way. The same remark is applicable where flaws are discovered in any of the main parts of the engine, whether they be malleable or cast iron; but they must be carefully watched, so that the engines may be stopped if the crack is extending further. Should fracture occur, the first thing obviously to be done is to throw the engines out of gear, and should there be much weigh on the vessel, the steam should at once be thrown on the reverse side of the piston, so as to counteract the pressure on the paddle-wheel.

These, then, are the most important of the points which suggest themselves in connection with the management of marine engines when they are at work; we have next a few remarks to offer upon the general management of the engine room, and upon the secret of economy in the working of steam vessels. In dealing with the firemen and coal trimmers, there must be as many *standing orders* as possible, so that the engineer may be saved a perpetual expenditure of thought on mere matters of routine, whereby his attention may be given to more important objects. The coal trimmers have usually the care of the lamps, the whole of which should be collected, cleaned, and trimmed every morning, and each then put in its proper place. For every thing in the engine room there should be a place, and for its being there, and being clean and fit for use, some person or other should be responsible. It appears to be expedient to give to the best fireman a few shillings a week more than the rest, and to make him responsible for all the spanners, the blocks for raising cylinder and air pump covers, and the screw for the paddle-wheels; and all these articles should be ranged, like the muskets of an armoury, upon the engine room bulk head. The spare gear should be ranged in the same situation, and should either be painted or be kept bright. The oil cans, lamps, and tallow kettles, may be put under the charge of the head coal trimmer; they should all be of brass of the same colour, and should be kept bright and clean. Of the oil tank, tallow locker, and waste chest, the engineer himself should keep the key, and should give out every morning the quantity allowed for the day's consumption. Bolts, copper drifts, and other light miscellaneous articles, the engineer should keep locked up in his store closet, where also he should keep his hammers and chisels, saws, drills, taps and dies, files, smith's tongs, and other similar implements. The paddle bolts and plates are in the charge of the carpenter, but the engineer should ascertain that the carpenter is always provided with a sufficient supply. Every steamer intended for the performance of other than short voyages, should be provided with a smith's forge and anvil, and with a small turning lathe. The smith's forge should be of a compact form, with the bellows situated beneath the hearth, and it should be set in a recess in the engine room, where it is always in sight; if stowed away in a dark place, the leather of the bellows will become mouldy and rotten. The engineer's store closet should be made with a glass door, so that any one visiting the engine room may see that the various articles in it are well taken care of, and that each is in its right place. The whole of the bolts about the engine of the same diameter should be made with the same pitch of screw, and the taps and dies supplied to the engineer should correspond therewith. Where there is a line of several vessels, it is most important that the whole of the engines should be the same, so that any one part of one engine may fit all the others. The boilers should also be of the same size, though they need not be of the same internal structure; and so soon as a boiler becomes much worn, it should be taken out and replaced by another, which is kept in readiness—the worn boiler being then thoroughly repaired ashore, and made fit for putting into another vessel. This plan is much more economical than that of executing heavy boiler repairs on board the vessel; and the beams above the boiler, the coal boxes, and all the boiler attachments, should be so contrived, that the boiler may be removed with facility. The firing tools and instruments for removing the deposit through the mudhole doors, are usually laid on hooks in the engine room, fixed against the side of the ship, and beneath these hooks the ash buckets and buckets for quenching the fires may be ranged. These buckets should be of strong sheet iron, with rims round top and bottom. The lamps used in the coal boxes and for cleaning the boilers, may be made of a short piece of malleable iron pipe staved up round at the one end, and with a bottom brazed in at the other, and short side pipes for the wicks may then be brazed on, which pipes should lead to near the bottom of the lamp; through a small hole in the top, a filling pipe should descend to near the bottom of the lamp, which may be furnished at the top with a projecting neck, on which a swivelling handle may be fixed. The oil is poured through the central pipe, and cannot be spilled though the lamp is turned upside down, nor can such a lamp be easily broken. The engineer will always require to carry glass gauge tubes with him, and the glass tube sockets should be so made that a tube may be put in at sea. The cocks connecting the glass tubes with the boiler, should be so made as to admit of the tubes being blown through with steam to clear them, as in muddy water they will become so much soiled, that it will be difficult to see the water. The whole of the articles of engine room furniture should be entered in a catalogue, and the engineer should be held responsible for their safe custody and preservation. The various engine room stores required, such as white and red lead, paint and paint oil, pasteboard, rope yarn, emery paper, Bath brick, brooms, shovels, and other articles, should all have their appropriate places in the store closet, and the engineer should, for his own satisfaction, keep an account of the consumption of them.

Steam vessels, to work economically, should have large engine power, with moderate boiler power; they should make as much use of sails as possible, and in fair winds or fine weather should work very expansively. In the case of adverse winds or tides, on the contrary, they should exert their full power, as it is only the excess of power possessed by a vessel over that requisite to stem an adverse wind or current, that is available for her propulsion; and the greater the power, the less will be the proportionate loss from her subjection to such influences. In fair winds, the engineer should use such a measure of expansion as will maintain the speed at about ten knots per hour; speeds materially higher than this are only got at a great proportionate expenditure of power; and in the generality of cases, the object, when this speed is obtained, should be not to increase the speed, but to save the fuel. Sails are far too little used in steam vessels: many captains never set them at all; but every sail unset when the wind is fair, involves an expenditure of fuel which might otherwise be saved. The resistance opposed to vessels moving through water increases as the square of the velocity, and the power requisite to overcome that resistance as the cube of the velocity; so that to double the speed takes eight times the power. The centre of pressure of the paddle boards should not move much more rapidly than the vessel moves through the water, else there will be a great loss of power from slip, — the power being wasted in forcing the water back from the wheel instead of being expended in forcing the vessel forward. The proportion of float-board, therefore, or the dip of the wheel, is an element of economy in the working of steam vessels, and must have reference to the power of the engine and the resistance experienced by the vessel. Four or five floats are usually immersed in the larger class of sea-going vessels; and with such a dip the engines are not subject to injurious fluctuations of speed from the roughness of the sea. The power exerted by an engine is of course greater when working fast than when working slow; but if the increased speed be obtained by an inadequate float surface, the increased power will be more than thrown away in churning the water; and the result will be an increased consumption of fuel with a diminished speed, or, in the most favourable case, with a speed not increased in anything near the ratio of the increased consumption of fuel.

The most beneficial amount of float surface having been determined, as may easily be done by trying the effect of different degrees of expansion if the float surface be too small, and by lightening the vessel or hoisting sail if it be too large, the floats should be firmly secured in their places; but it may be taken as a general rule, that the *horizontal* speed of the entering float must be as great as that of the ship, else the entering float will carry a sea before it, as is done by the bow, and will impede as well as aid the vessel's progress. The steam pipes should be clothed with felt and covered with wood, and the cylinders and boilers should also be effectually clothed, as has been already stated, so as to prevent the dispersion of heat, and to keep the engine room cool. Care must be taken that the pistons and valves do not leak steam, which would greatly increase the consumption of fuel; and their tightness should be occasionally tested by lifting the covers and letting the steam in below the valves and pistons. The engineer should assure himself, when getting coals on board, that he really receives the quantity professed to be given, and one of the engineers should see the whole quantity weighed; he should also compute the capacity of the coal-boxes, as an additional check, and if they hold too much he may be tolerably sure that he has not received his quantity. The density of coal varies somewhat; the bushel of Welsh coal being 94 lbs., while the bushel of Staffordshire coal is only 84 lbs.; but it is an easy thing for the engineer to weigh a vessel of the coal, of any given capacity in cubic feet, from whence the weight of any other number of cubic feet can readily be determined. On the average, a ton of coal occupies a measured ton of stowage. If the coals occupy more than the computed space, the inference is that they are badly stowed. Long furnaces are generally more extravagant in coal than short furnaces; and many cases might be mentioned where shortening the furnaces has been attended with an increased generation of steam, as well as with a saving of fuel. A great economy, both in fuel and in wages, would be accomplished if marine boilers were to be fired by machinery instead of by hand, and an important benefit to steam navigation would be achieved by the practical introduction of this improvement.

The expedients of economy here enumerated will certainly be productive of important results if effectually carried into practice, yet we should not be disposed to trust implicitly to these or any other recipes, but would seek to enlist the interests of the engineer and captain in the success of any projected scheme of economy. We therefore recommend to more general adoption the system of giving the captain and engineer a share in the savings of coal that they accomplish; and we should further give the engineer a share of any savings in the consumption of oil, tallow, or other stores, that he can effect. We include the captain in the award of the savings of fuel, because by his exertions the saving may be materially increased; for the engineer's exertions may be in a great measure defeated, if the captain neglects to hoist sail, or pursues zig-zag courses. It would be still preferable, however, for steam companies, if they could contract for the maintenance of the propelling power with some responsible party, who would make the development of all measures of increased efficiency and economy a business, and would thus be more likely to work them effectually out, and who could make the necessary bargains with captains and engineers. We believe that companies would derive a similar benefit from this arrangement to that experienced by the government, when it let out by contract the conveyance of the mails. The expense of every steam vessel running would thus be a determinate thing, and the company would be able to give its exclusive attention to what is after all its legitimate function, — that of increasing its profits, and improving its commercial position. The appetite for power and patronage prevailing among the managers of companies may defeat, in some cases, such an innovation; but we believe that it will eventually become a general arrangement, and one that will be found beneficial to both of the contracting parties. In the case of railway locomotion it is already extensively practised, and is found to be attended with satisfactory results.

MANAGEMENT OF LOCOMOTIVES.

The most important part of the engine-driver's duty is, the observance of signals, respecting which no general rules can be given, as the systems of signals vary upon different railways; but a strict attention to the signals fixed upon, and a constant watchfulness to see that the rail is free from obstruction, constitute the most important part of the duty the engine-driver has to perform. He should constantly be upon the foot-board of the engine, so that the regulator, the whistle, or the reversing handle may be used instantly, if necessary. At the same time he must see that the level of the water in the boiler is duly maintained, and that the steam is kept at a uniform pressure. In feeding the boilers with water, and the furnaces with fuel, a good deal of care and some tact are necessary, as irregularity in the production of steam will often occasion priming, even though the water be maintained at a uniform level; and an excess of water will of itself occasion priming, while a deficiency is a source of obvious danger. The engine is generally furnished with three gauge-cocks, and water should always come out of the second gauge-cock, and steam out of the top one, when the engine is running; but when the engine is at rest, the water in the boiler is rather lower than when it is in motion; so that when the engine is at rest the water will be high enough if it just reaches to the middle gauge-cock. The boiler should be well filled with water on approaching a station; as there is then steam to spare, and additional water cannot be conveniently supplied when the engine is stationary. The furnace should be fed with small quantities of fuel at a time, and the feed should be turned off just before a fresh supply of fuel is introduced. The regulator may at the same time be partially closed, and if the blast-pipe be a variable one, it will be expedient to open it widely while the fuel is being introduced, to check the rush of air in through the furnace door, and then to contract it very much so soon as the furnace door is closed, in order sooner to recover the fire. The proper thickness of coke upon the grate depends upon the intensity of the draft; but in heavily loaded engines it is usually kept up to the bottom of the fire door. Care, however, must be taken that the coke does not reach up to the bottom row of tubes, so as to choke them up. The fuel is usually disposed on the grate like a vault, and if the fire box be a square one, it is heaped high in the corners, the better to maintain the combustion. In starting from a station, and also in ascending inclined planes, the feed water is generally shut off; and therefore, before stopping or ascending inclined planes, the boiler should be well filled up with water. In descending inclined planes, an extra supply of water may be introduced into the boiler, and the fire may be fed, as there is at such times a superfluity of steam. In descending inclined planes, the regulator must be partly closed; and it should be entirely closed, if the plane be very steep. The same precaution should be observed in the case of sharp curves or rough places on the line, and in passing over points and crossings. To ascertain whether the pumps are acting well, the pet-cock must be turned, and if any of the valves stick, they will sometimes be induced to act again by working with the pet-cock open, or alternately open and shut. Should the defect arise from a leakage of steam into the pump, which prevents the pump from drawing, opening the pet-cock remedies the evil, by permitting the steam to escape. Should priming occur, from the water in the boiler being dirty, a portion of it may be blown out; and should there be much boiling down through the glass gauge tube, the top cock may be partially closed. The water should be wholly blown out of locomotive boilers three times a week; and at those times two mud-holes, at opposite corners of the boiler, should be opened, and the boiler be washed internally by means of a hose.

On approaching a station, the regulator should be gradually closed, and it should be completely shut at about half-a-mile from the station if the train be a heavy one, and the train may then be brought to rest by means of the breaks. Too much reliance, however, must not be put upon the breaks, as they sometimes give way, and in frosty weather are nearly inoperative. In cases of urgency the steam may be thrown upon the reverse side of the piston, but it is desirable to obviate this necessity as far as possible. At terminal stations the steam should be shut off earlier than at roadside stations, as a collision will take place at terminal stations if the train overshoots the place at which it ought to stop. There should always be a good supply of water when the engine stops, but the fire may be suffered gradually to burn low towards the conclusion of the journey. So soon as the engine stops, it should be wiped down and be then carefully examined. The brasses should be tried to see whether they are slack or have been heating; and it should be ascertained occasionally whether the wheels are square on their axles, by the application of a gauge, and whether the axles have end play, which should be prevented. The stuffing-boxes must be tightened, the valve-gear examined, and the eccentrics be occasionally looked at to see that they have not shifted on the axle, though this defect will generally be intimated by the irregular beating of the engine; the tubes should also be examined and cleaned out, and the ashes emptied out of the smoke-box through the small ash-door. If the engine be a six-wheeled one, it will be liable to pitch and oscillate if too much weight be thrown on the driving-wheels, and where such faults are found to exist, the weight upon the driving-wheels should be diminished. The practice of blowing off the boiler by the steam, as is always done in marine boilers, should not be permitted, as a general rule, in locomotive boilers when the tubes are of brass and the fire-box of copper; but where the tubes and fire-boxes are of iron, it may safely be done. Before starting on a journey, the engine-man should take a summary glance beneath the engine, but ought first to assure himself that no other engine is coming up at the time. The regulator, when the engine is standing, should be closed and locked, the eccentric-rods be fixed out of gear, and the tender break secured down; the cocks of the oil vessels should at the same time be shut, but should all be opened a short time before the train starts.

Most of the accidents attended with loss of life upon railways have been occasioned by persons jumping on or off the train whilst in motion, and many cases might be cited of engine drivers and stokers having been killed by falling off the engine, — in some cases from the coupling of the engine and tender suddenly giving way. The most frequent causes of collision are fogs and the absence of a uniformity of time at the different stations along the line, in consequence of their difference of longitude. Collisions have sometimes occurred from carriages having been blown from a siding upon the rails by a high wind; and the slippery state of the rails or the fracture of a break, has in some cases caused collision at terminal stations. Collision has also taken place from one engine having overtaken another in consequence of the imperfect condition of the first engine from a leaky tube or otherwise. When a tube bursts, a wooden or iron plug must be driven into each end of it, and if the water or steam be rushing out so fiercely that the exact position of the imperfection cannot be discovered, it will be advisable to diminish the pressure by increasing the supply of feed water. Should the leak be so great that the level of the water in the boiler cannot be maintained, it will be expedient to drop the bars and quench the fire, so as to preserve the tubes and fire-box from injury. Should the wooden casing of the boiler catch fire, it may be extinguished by throwing a few buckets of water upon it, or if the engine is at a station, it may be brought under the water crane. Should the piston rod or connecting rod break, or the cutters fall out or be clipped off, as sometimes happens to the piston cutter when the engine is suddenly reversed upon a heavy train, the parts should be disconnected if the connection cannot be restored, so as to enable one engine to work, and of course the valve of the faulty engine must be kept closed. If one engine has not power enough to enable the train to proceed with the blast pipe full open, the engine may perhaps be able to take on a part of the carriages, or it may run on by itself to fetch assistance. The same course must be pursued if any of the valve gearing becomes deranged and cannot be rectified upon the spot.

Before leaving a station the engine driver should always assure himself that he has the requisite supply of coke and water, and should not trust to the attention of the stoker respecting such matters. Besides the firing tools and rakes for clearing the tubes, he should have with him in the tender a small oil tank and a small tallow chest, a box of waste, some rope yarn, gasket, canvass, and whitelead; two small oil casks, an oil syringe, spanners, and one shifting key; a chipping hammer, chipping chisels, and a file; a coal hammer, some wooden and iron plugs, and an iron plug holder, a sheet-iron bucket, a screw jack, two crow bars, a chain, and some wooden wedges. The whole of these articles should be arranged in the tender in suitable places, so that the engine driver may know where to put his hand upon any article, and can see at a glance whether any of them is missing. A few spare bolts of different sizes should also be carried. To economise fuel in locomotives, a variable expansion gear is very desirable, which may be adjusted to the load, and the blast pipe must be worked with the least possible contraction. At stations the damper should be closed to prevent the dissipation of the heat. Anthracite has been tried for locomotives instead of coke, but it crumbles down into a powder, and forms a compact mass upon the bars which prevents the admission of an adequate supply of air to the furnace. If the area of grate be enlarged, however, it appears probable that anthracite may be used if mixed with coke. Upon some railways premiums are given to the engine drivers for economising fuel. The practice appears to us to be commendable enough, but it should be coupled with the publication of the consumption of the locomotives of different makers, as no amount of care on the part of the engine driver will suffice to correct the vices of an imperfect machine.

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THE END.

London:
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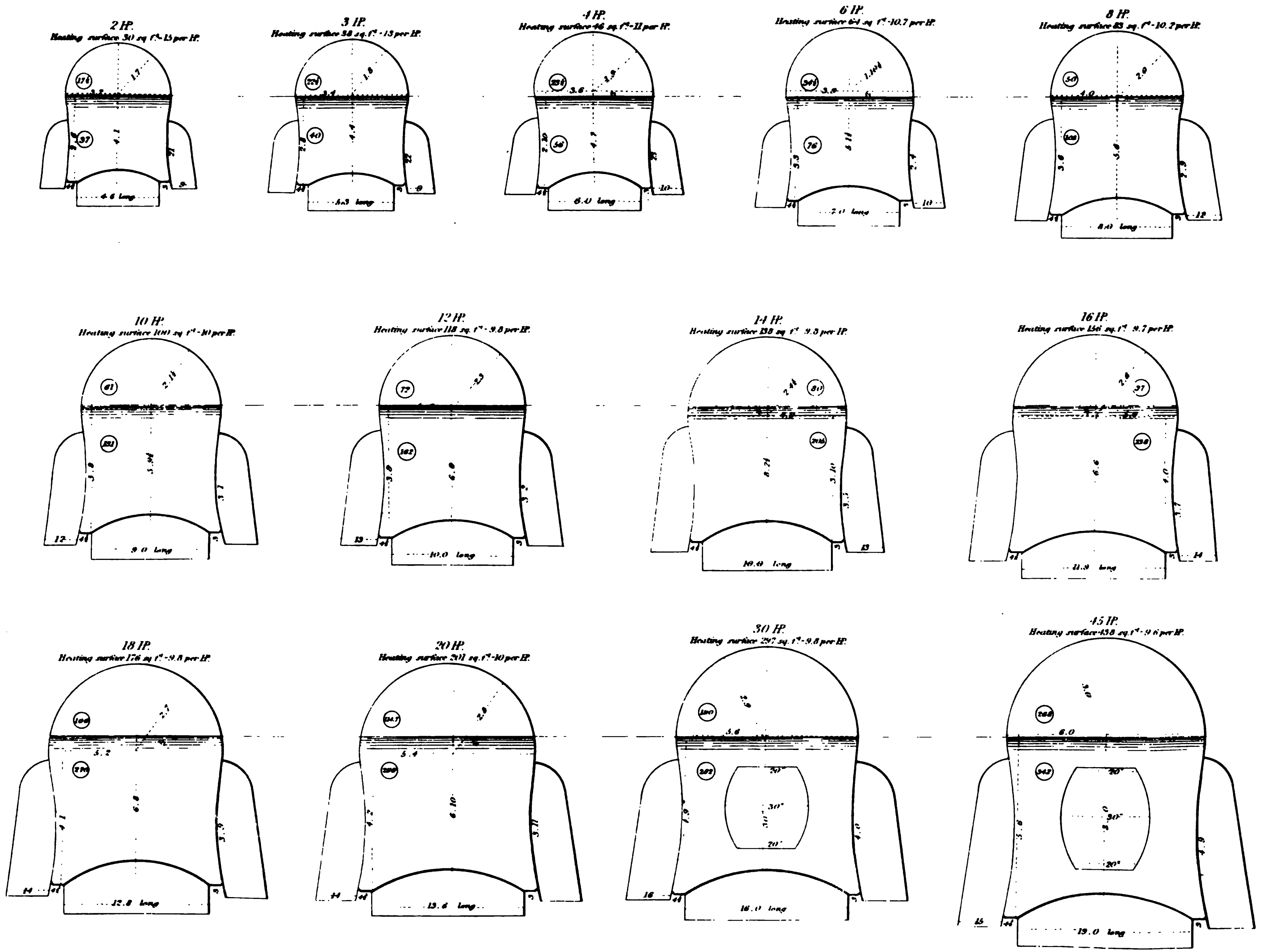
LAND BOILERS OF MESSRS BOULTON, WATT [illegible]

Scale [illegible]


2 HP.
Heating surface 30 sq. ft. -15 per HP.
4.6 long
3 HP.
Heating surface 38 sq. ft. -13 per HP.
5.3 long
4 HP.
Heating surface 46 sq. ft. -11 per HP.
6.0 long
6 HP.
Heating surface 64 sq. ft. -10.7 per HP.
7.0 long
8 HP.
Heating surface 83 sq. ft. -10.2 per HP.
8.0 long
10 HP.
Heating surface 100 sq. ft. -10 per HP.
9.0 long
12 HP.
Heating surface 118 sq. ft. -9.8 per HP.
10.0 long
14 HP.
Heating surface 138 sq. ft. -9.8 per HP.
10.0 long
16 HP.
Heating surface 156 sq. ft. -9.7 per HP.
11.0 long
18 HP.
Heating surface 176 sq. ft. -9.8 per HP.
12.8 long
20 HP.
Heating surface 201 sq. ft. -10 per HP.
13.6 long
30 HP.
Heating surface 297 sq. ft. -9.8 per HP.
16.0 long
45 HP.
Heating surface 438 sq. ft. -9.6 per HP.
19.0 long

The figures enclosed in the small circles in the steam and water spaces represent the number of cubic feet of steam and of water in the boiler respectively.

H. Adlard sc.

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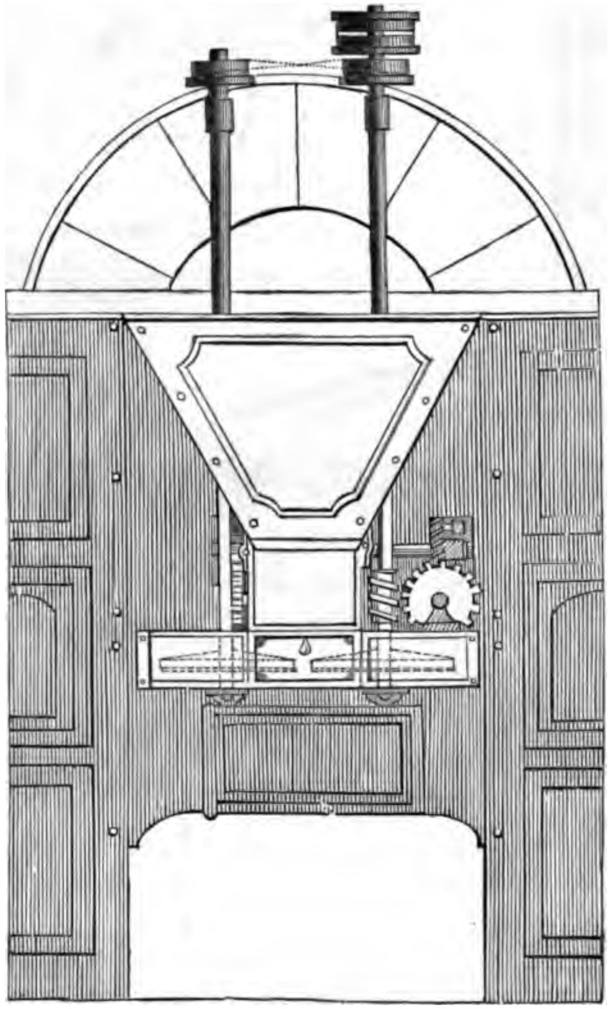
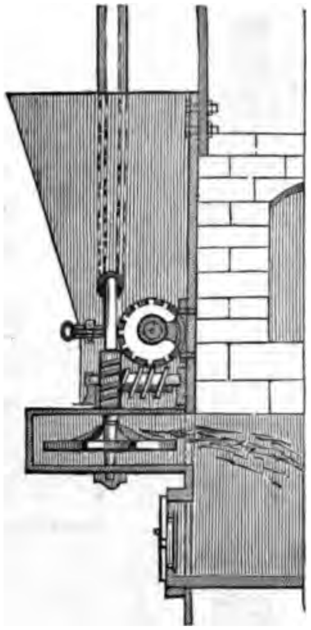
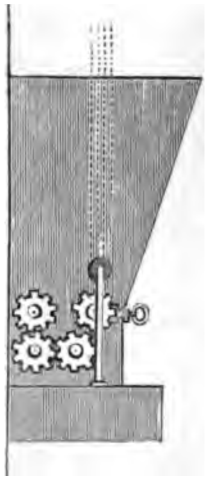
STANLEY'S FURNACE-FEEDING MACHINE.



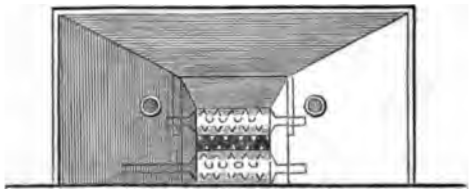
FRONT ELEVATION.



RIGHT HAND SIDE VIEW, WITH SECTION OF FAN-BOX AND FURNACE.



LEFT HAND SIDE VIEW OF HOPPER.



TOP VIEW OF HOPPER.

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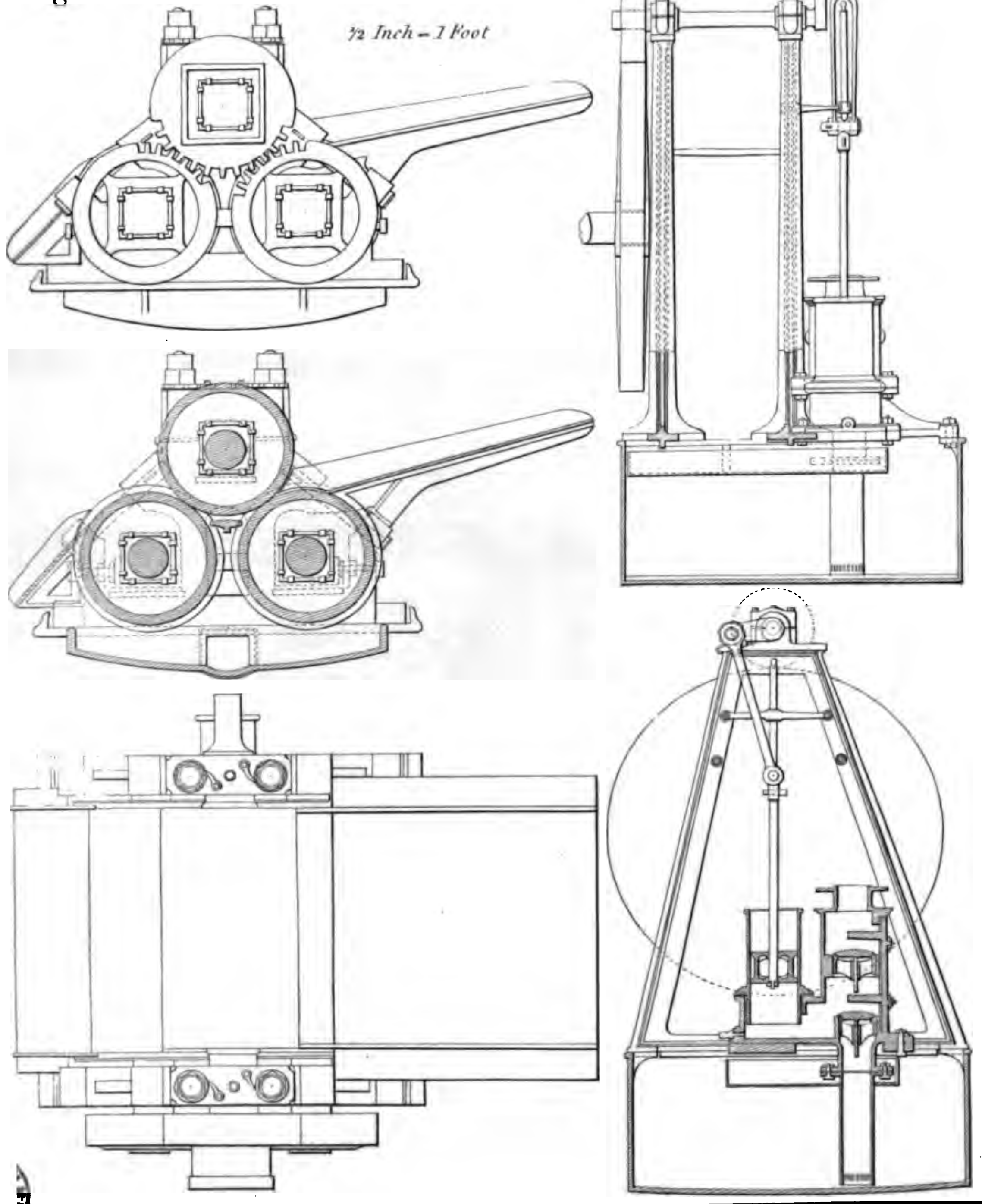
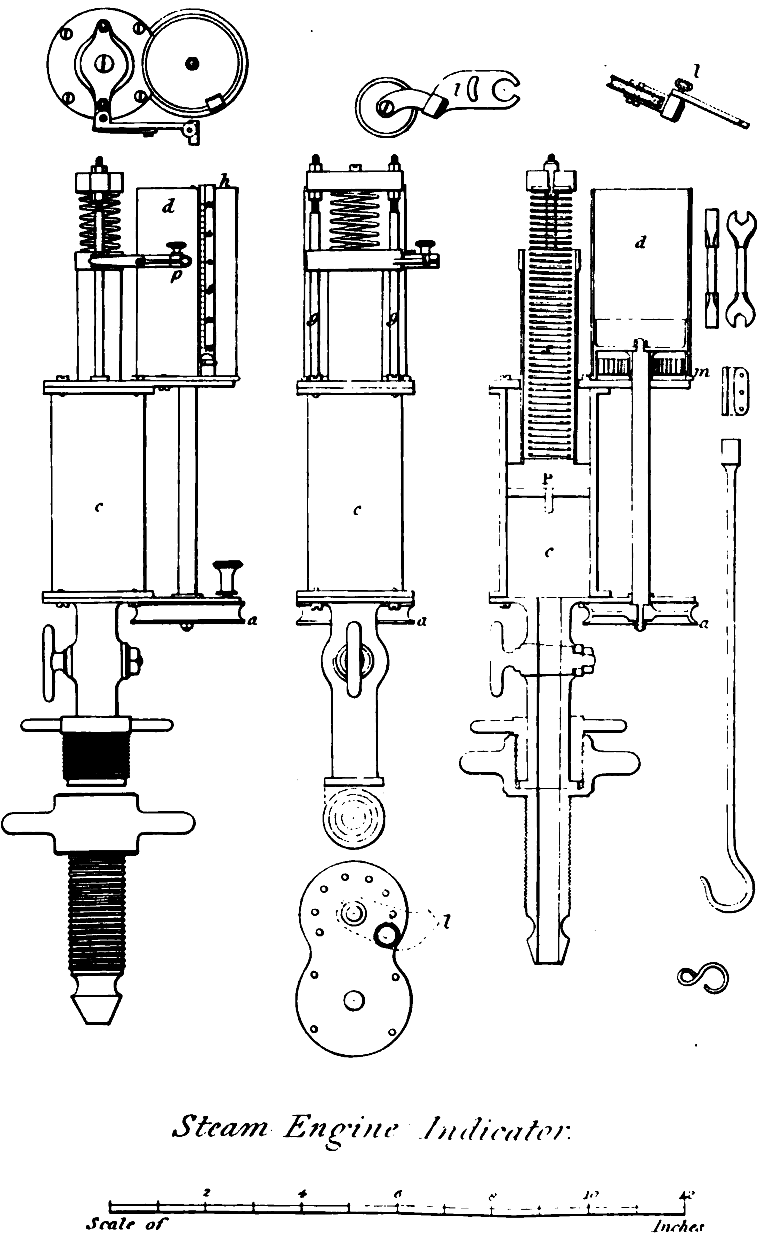
Sugar. Mill by Claude Girdwood & Co.

½ Inch = 1 Foot





Steam Engine Indicator.

F. Mansell. sc.

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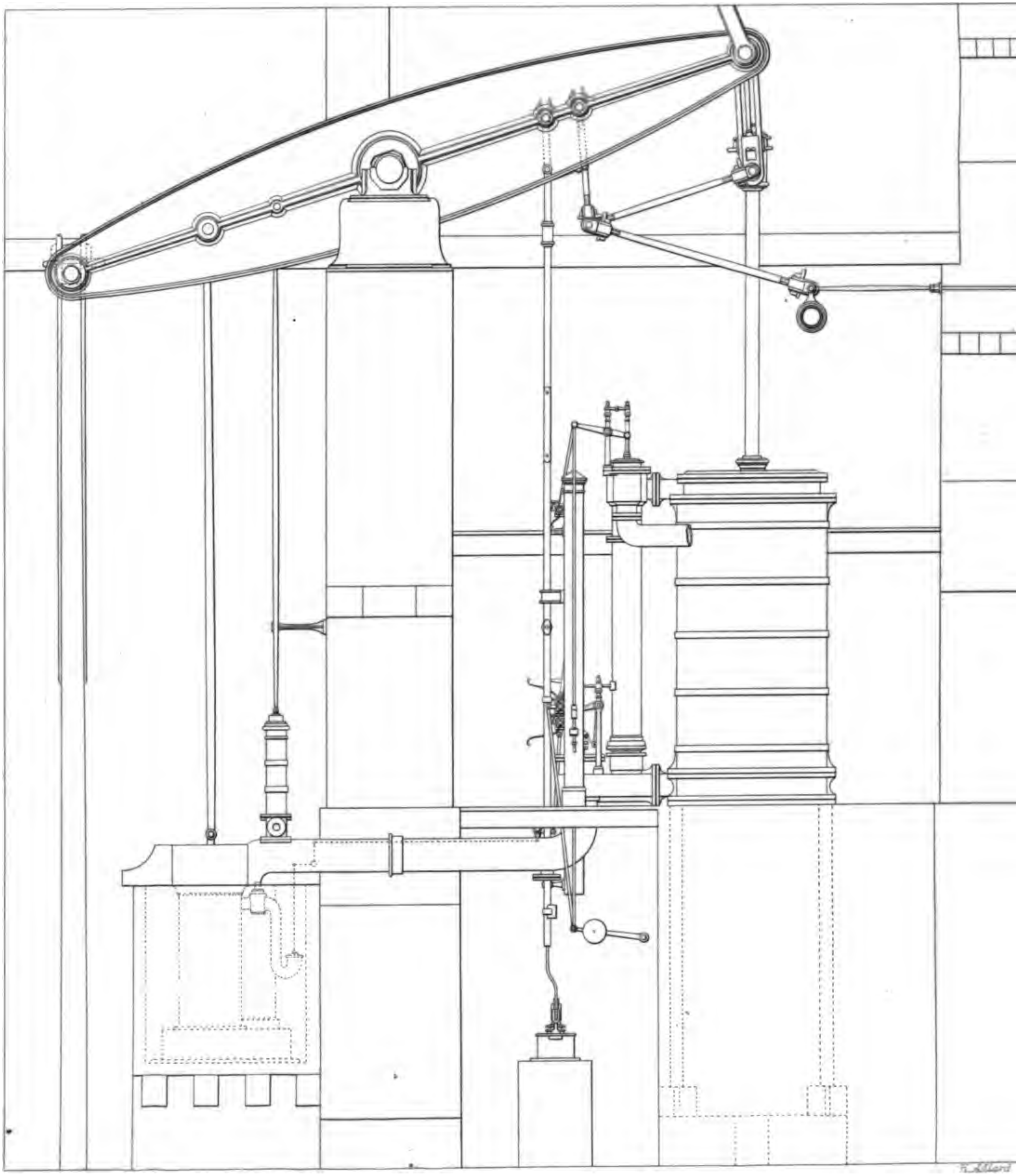
CORNISH PUMPING ENGINE
Hayle Foundry

PLATE



Scale of Feet

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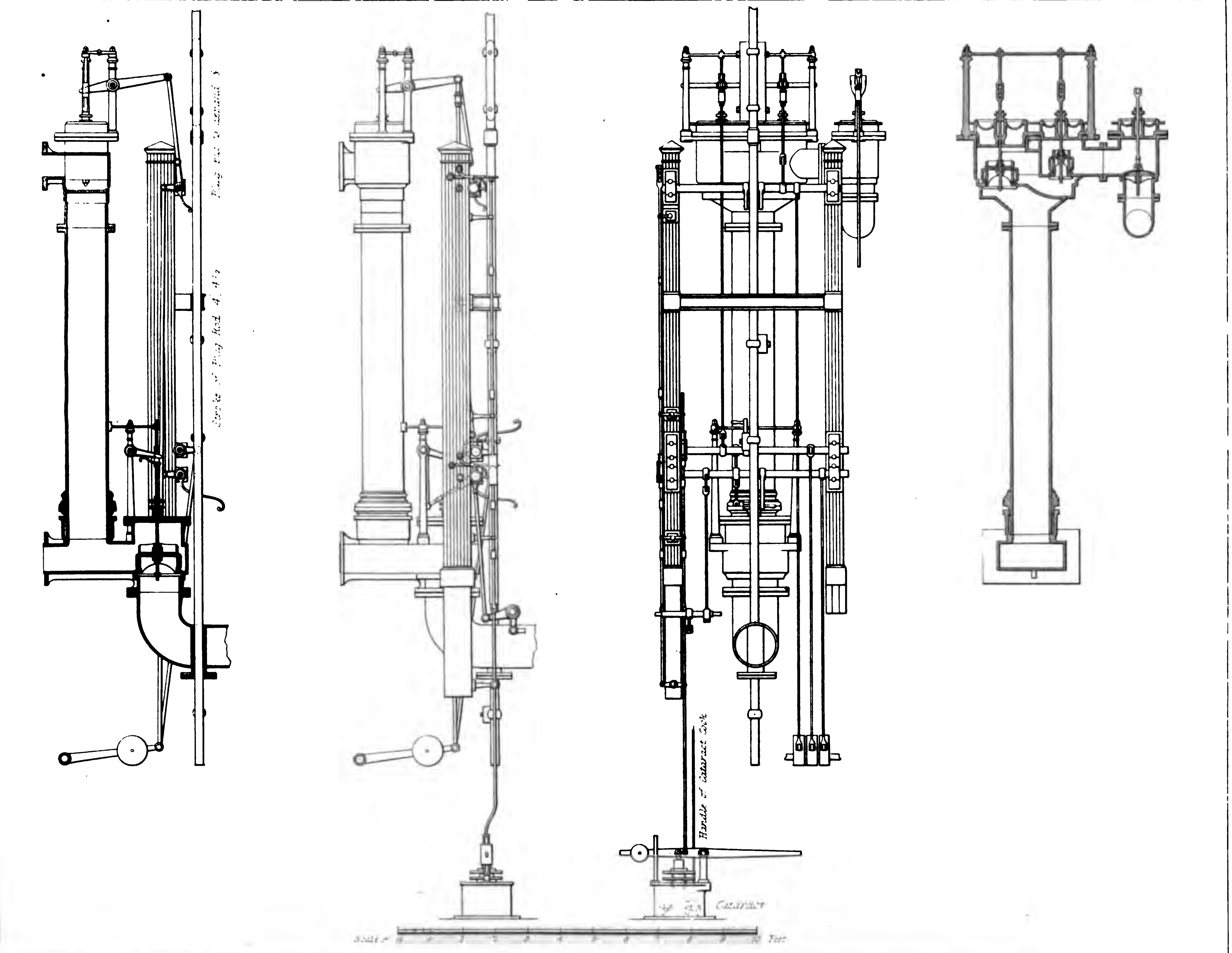
UNI

Hayle Foundry

PLATE VI



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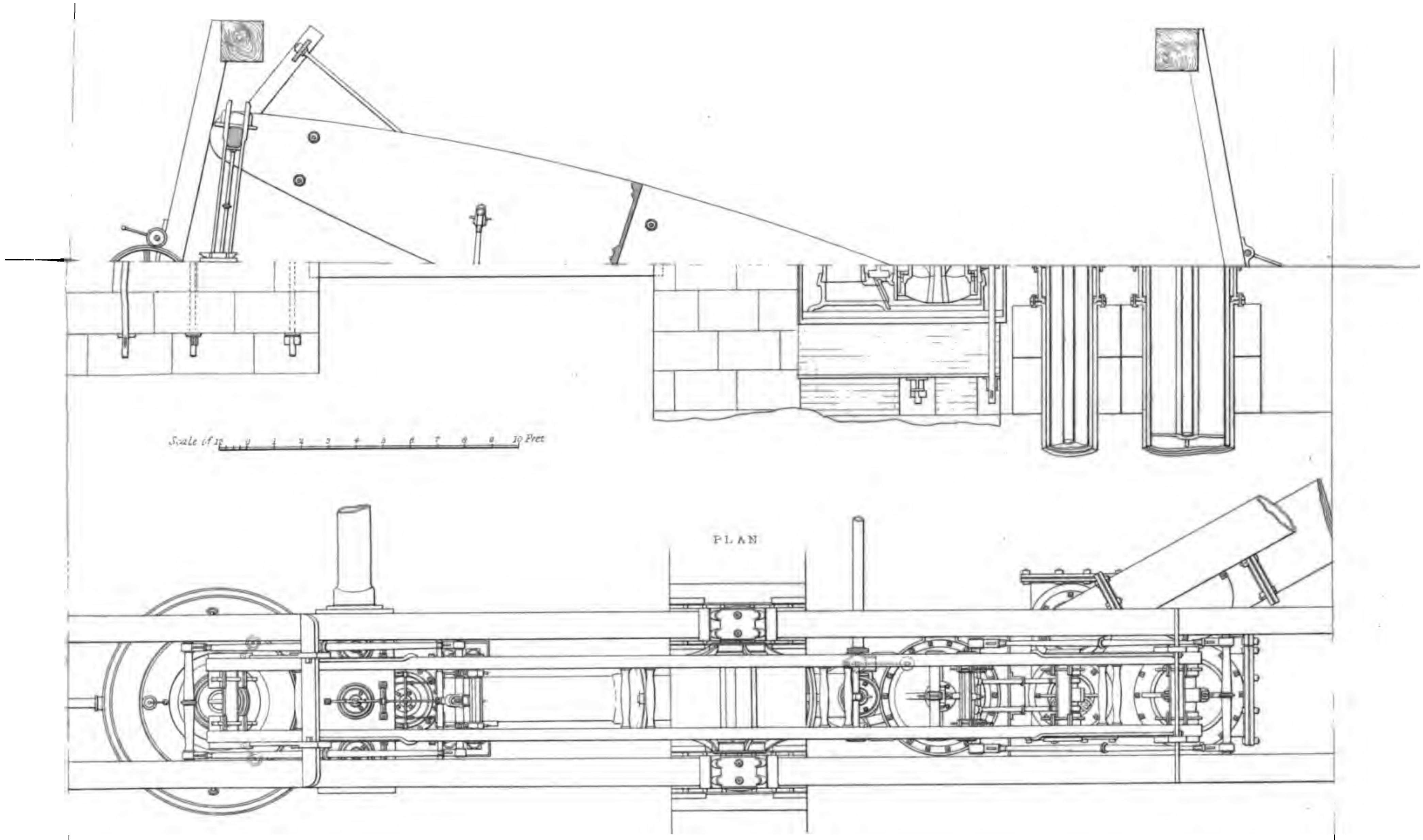
UNIV. OF

PUMPING ENGINE AT VAUXHALL WATERWORKS.

R Hosking Engineer

PLATE VII



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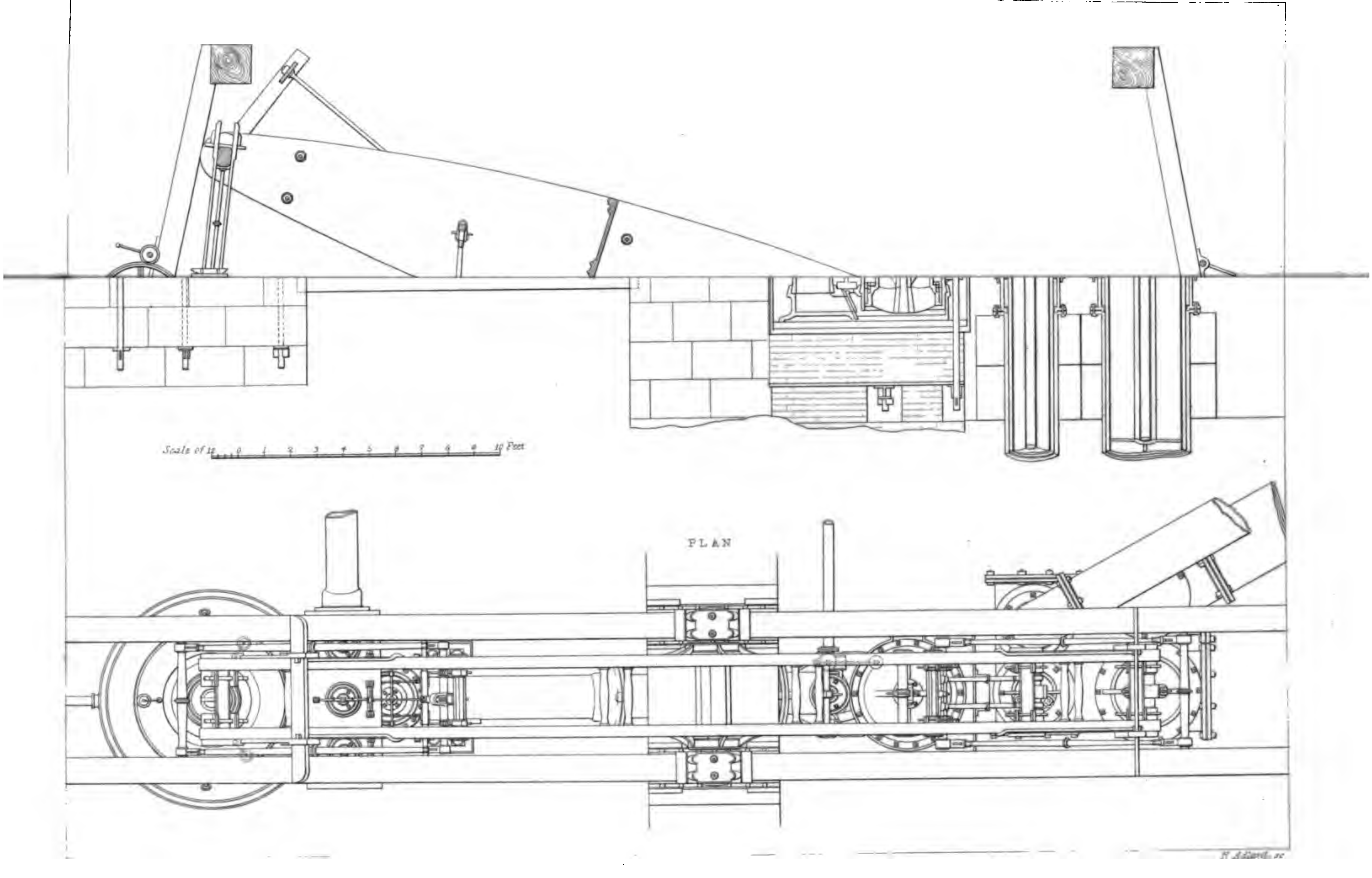
PUMPING ENGINE AT VAUXHALL WATERWORKS,

R. Hosking, Engineer

PLATE VII



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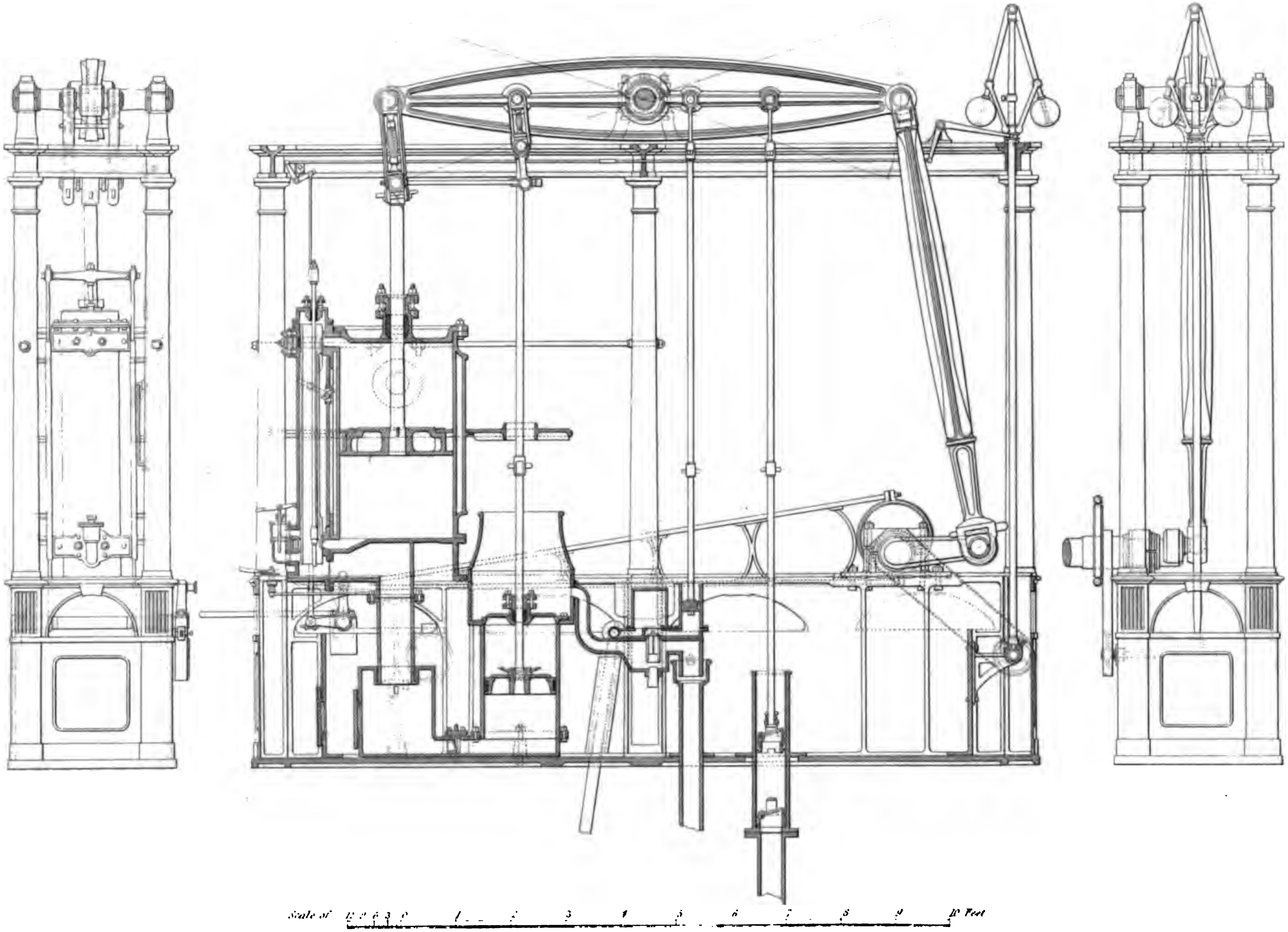

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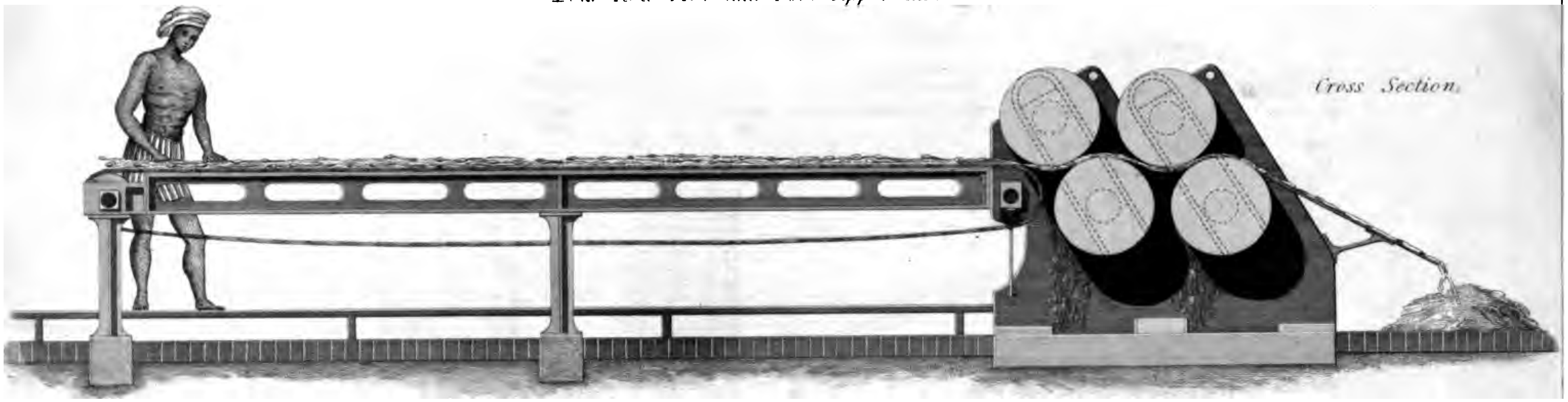
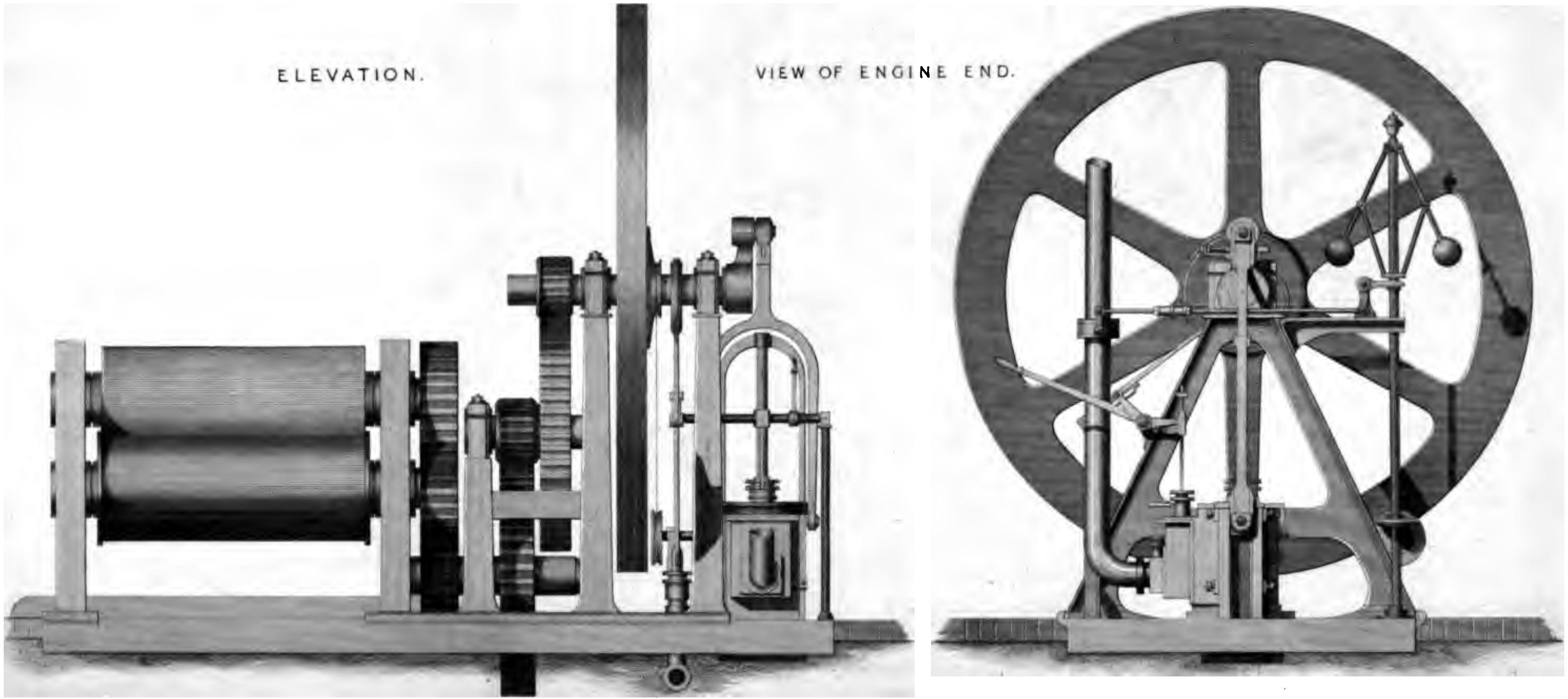
Patent Steam Cane Mill. — by Mess^rs H. O. & A. Robinson, Millwall Works.

Four Roll Mill and Feed Apparatus. —





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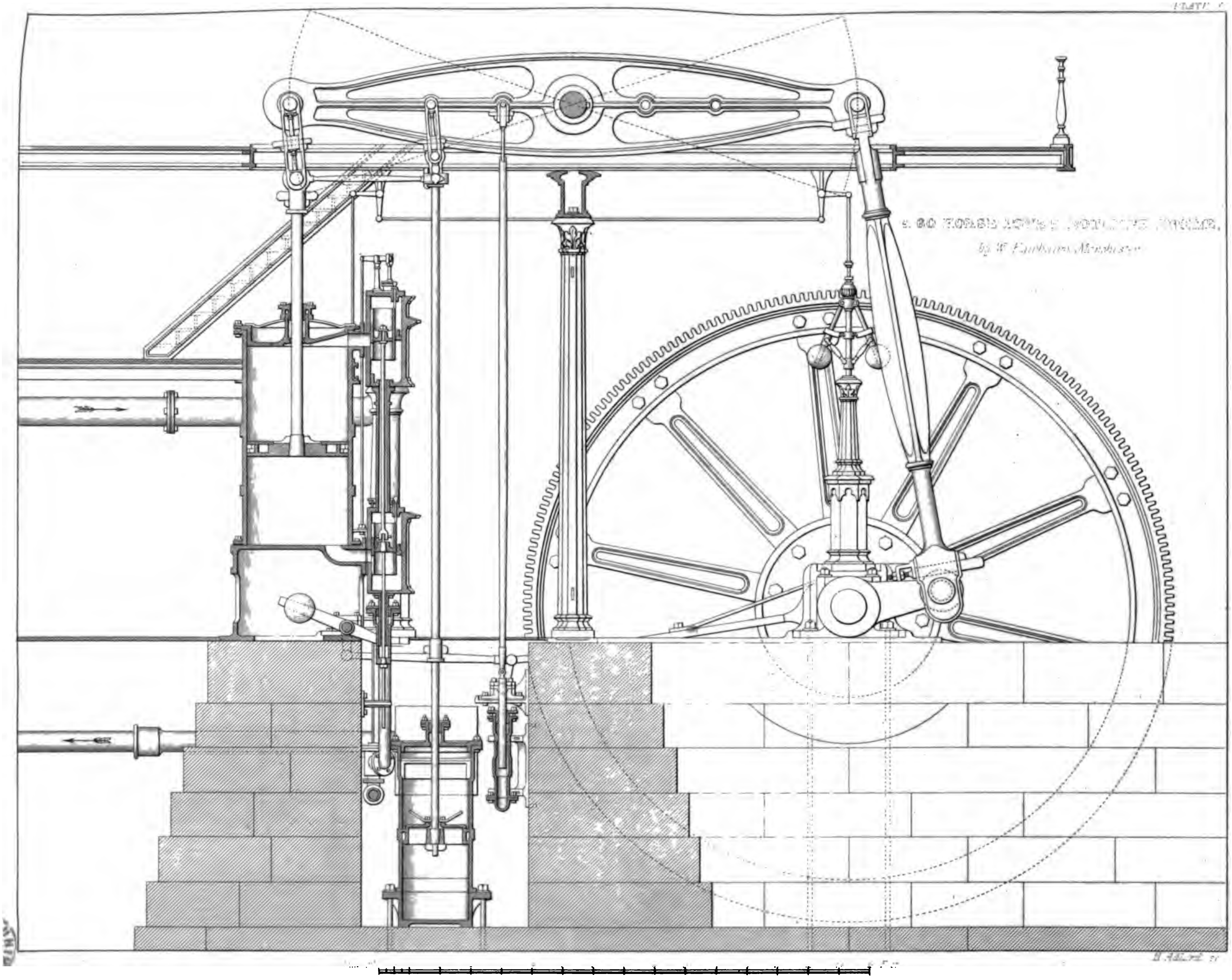
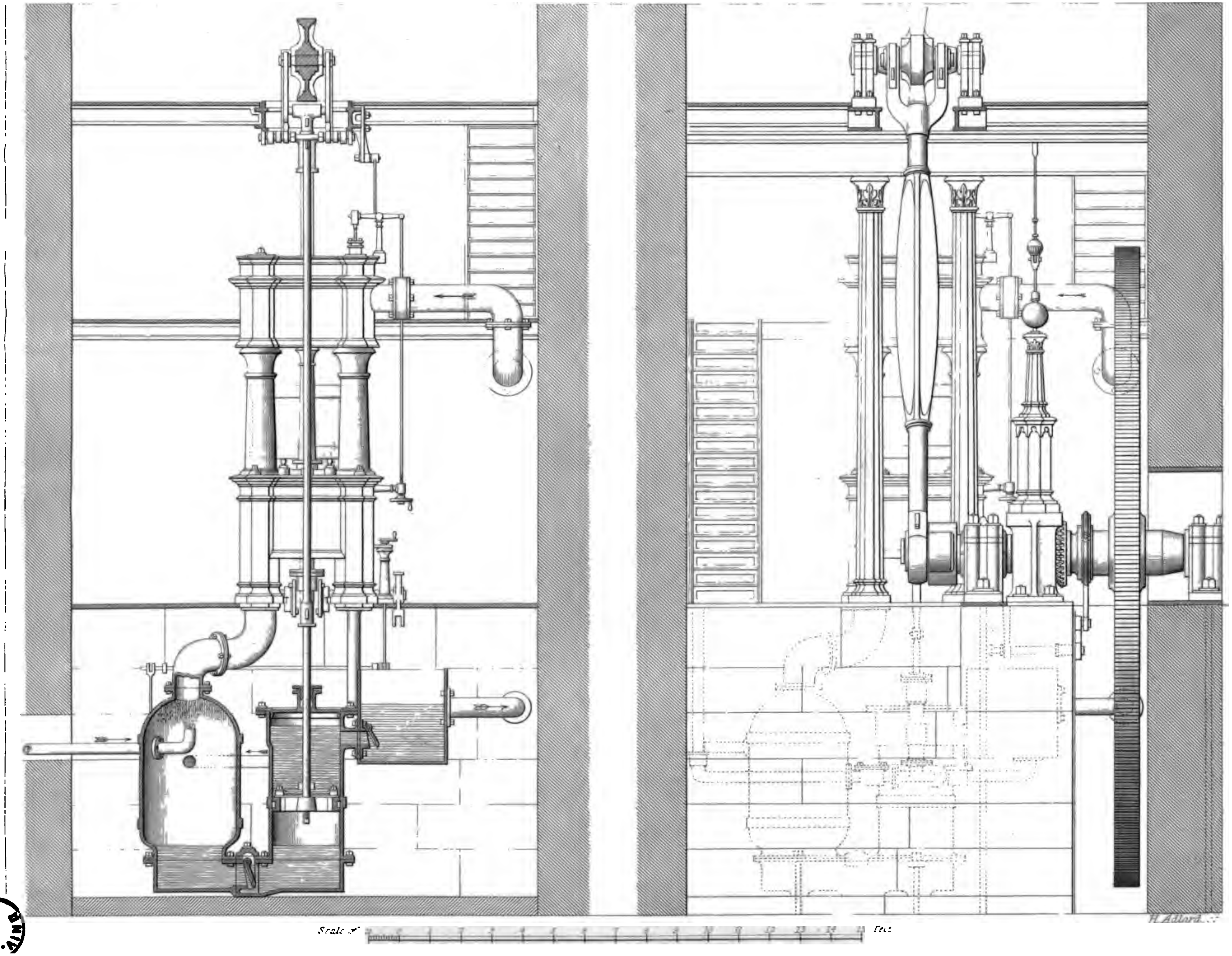


A 60 HORSE POWER CONDENSING ENGINE,

by W. Fairbairn, Manchester.

W. Fairbairn, Manchester

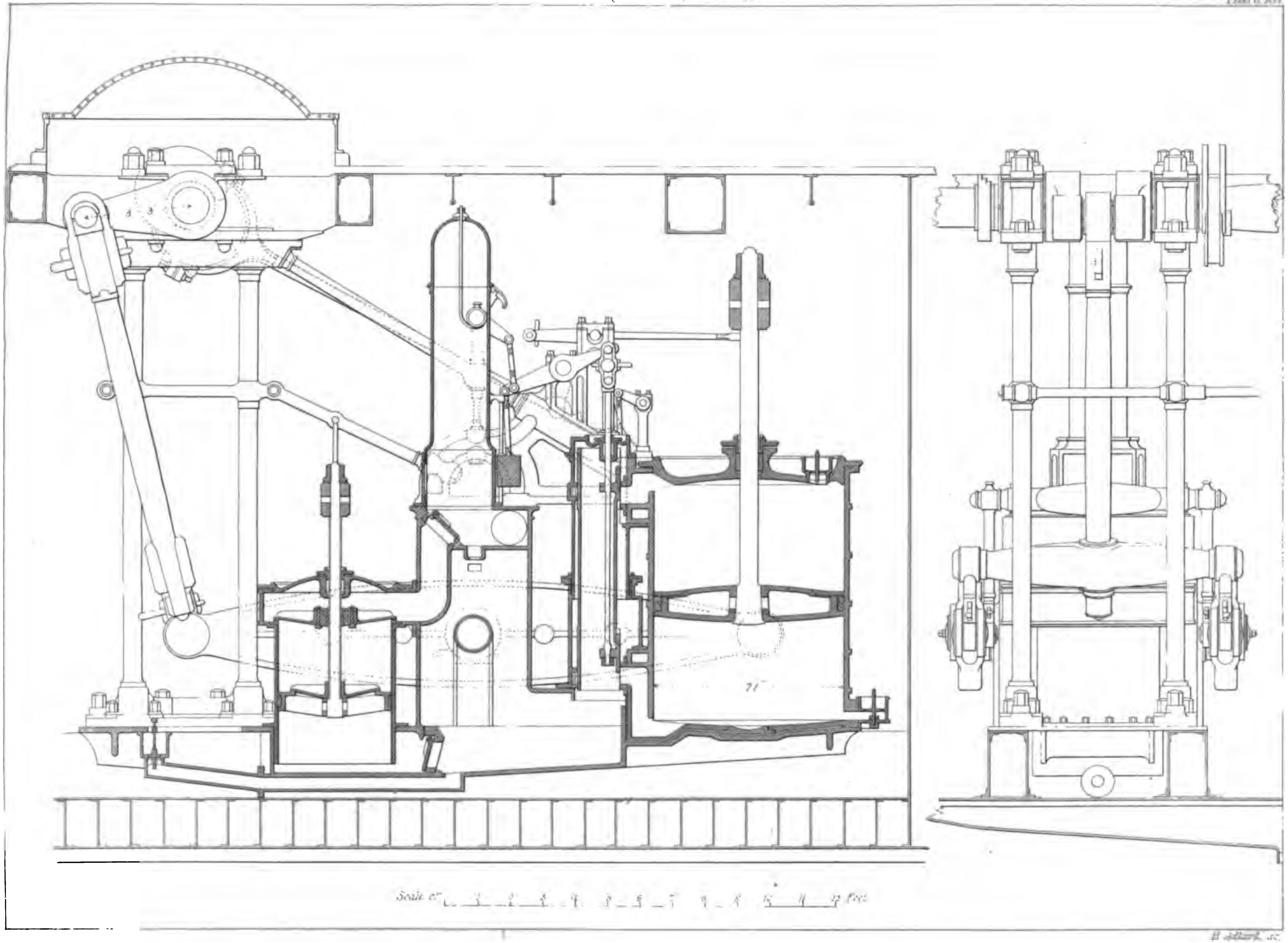


H. Adlard sc.

UNIV. OF MICH.

SECTION AND END VIEW OF ONE OF THE ENGINES OF THE STEAM SHIP CITY OF LONDON.

Constructed by R. Napier Glasgow



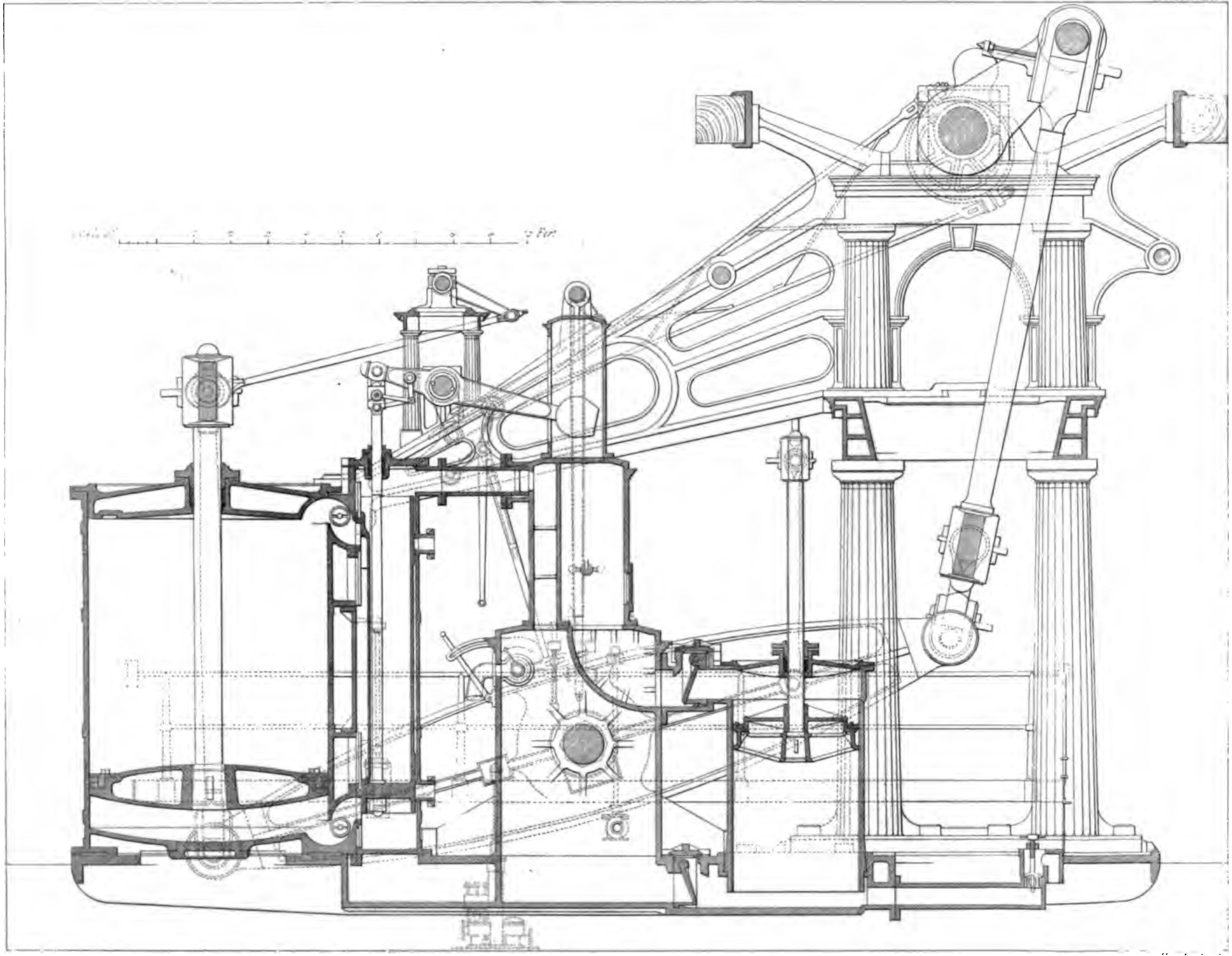
H. Adlard, sc.

London. Longman, Brown, Green & Longmans

ENGINES OF THE STEAMERS, CLYDE, TWEED, TAY AND TEVIOT.

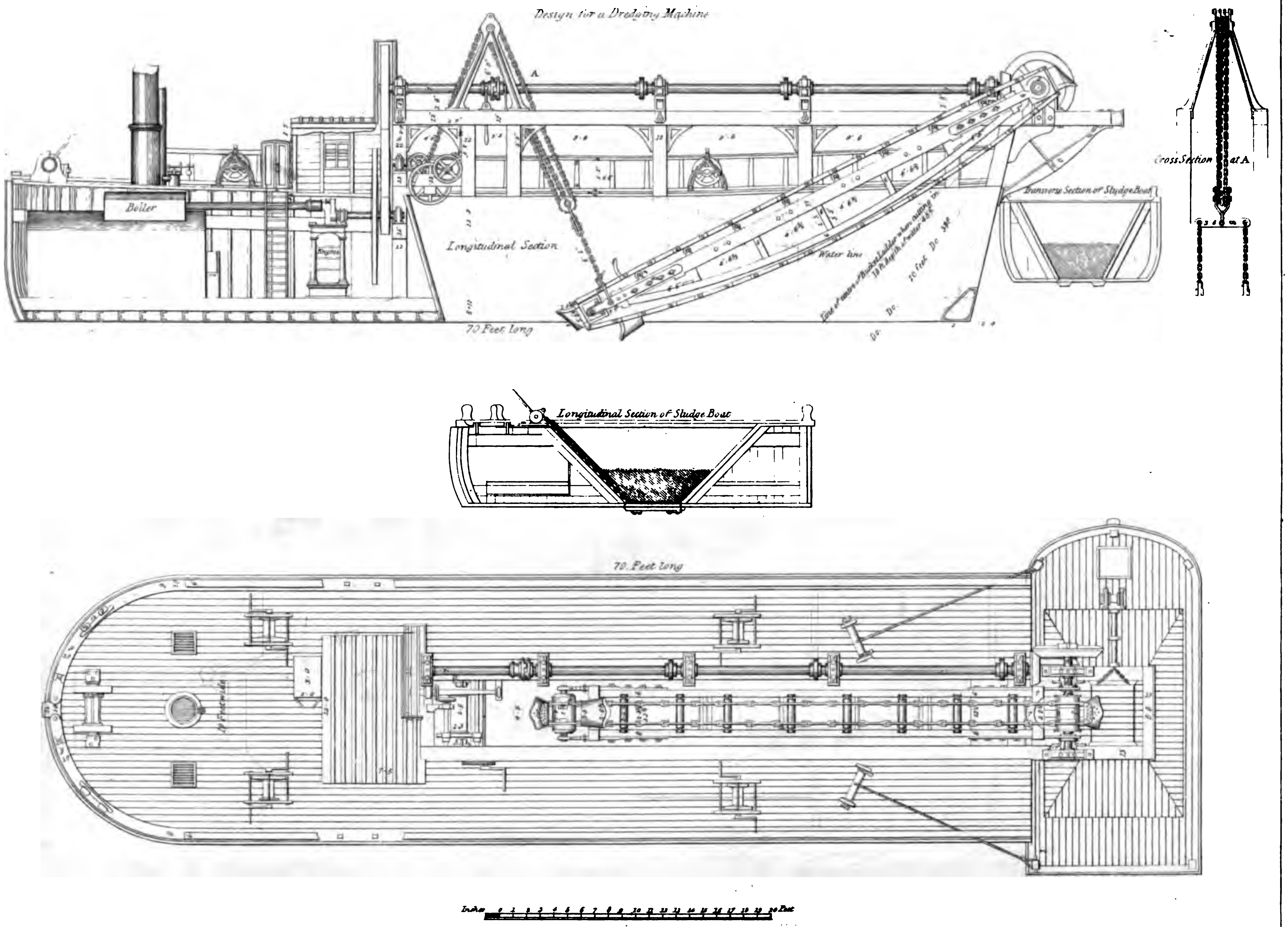
by Caird & Co Greenock

PLATE XIII



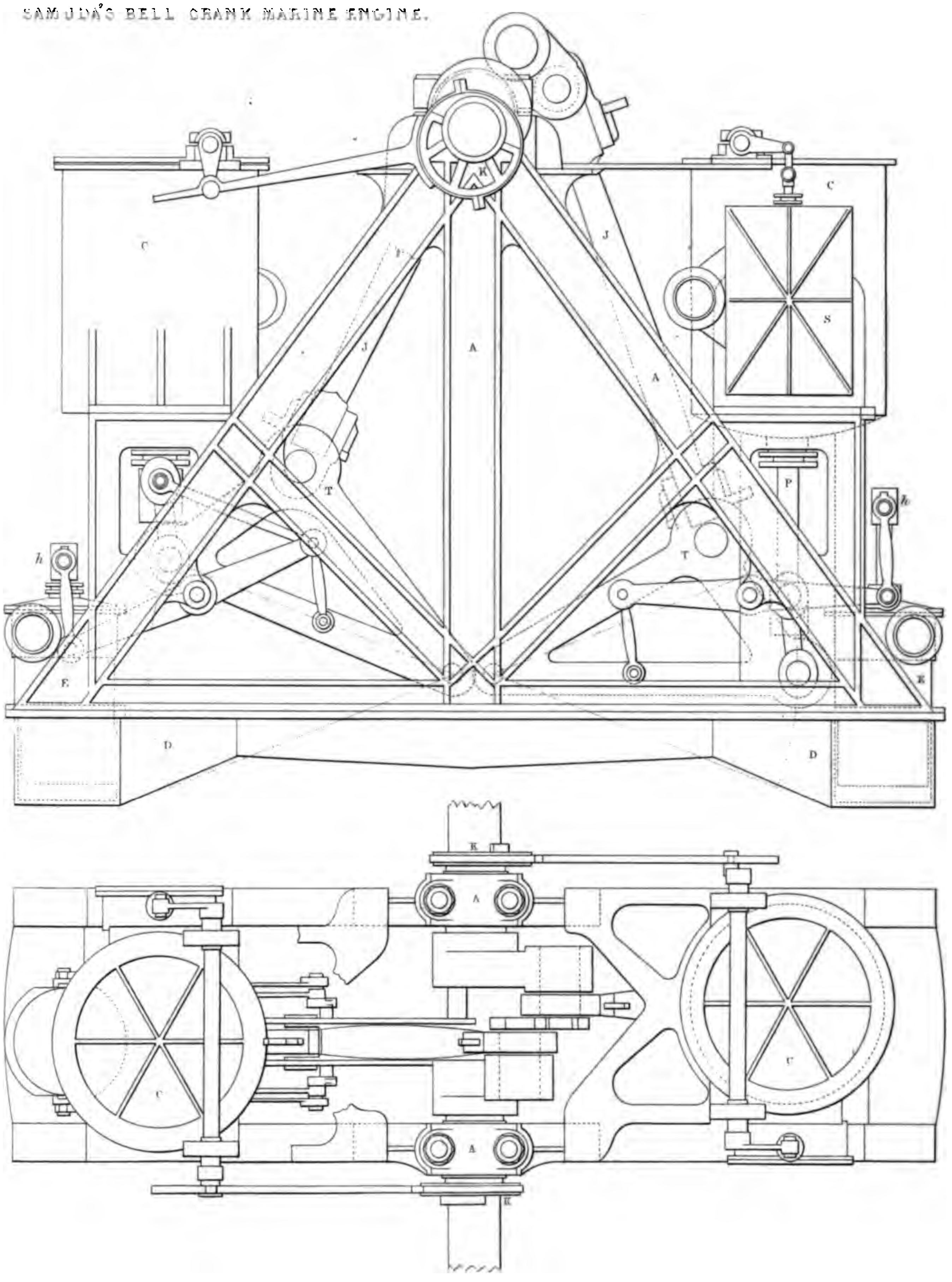
London, Longman, Brown, Green & Longmans.

Design for a Dredging Machine


A
Boiler
Engine
Longitudinal Section
Water line
Line of centre of Bucket Ladder when cutting in 18 ft. depth of water 48 ft.
20 feet Do 38°
Do.
Do.
70 Feet long
Cross Section at A
Transverse Section of Sludge Boat
Longitudinal Section of Sludge Boat
70 Feet long
Inches 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 Feet

London, Longman, Brown, Green & Longmans.

SAMUDA'S BELL CRANK MARINE ENGINE.

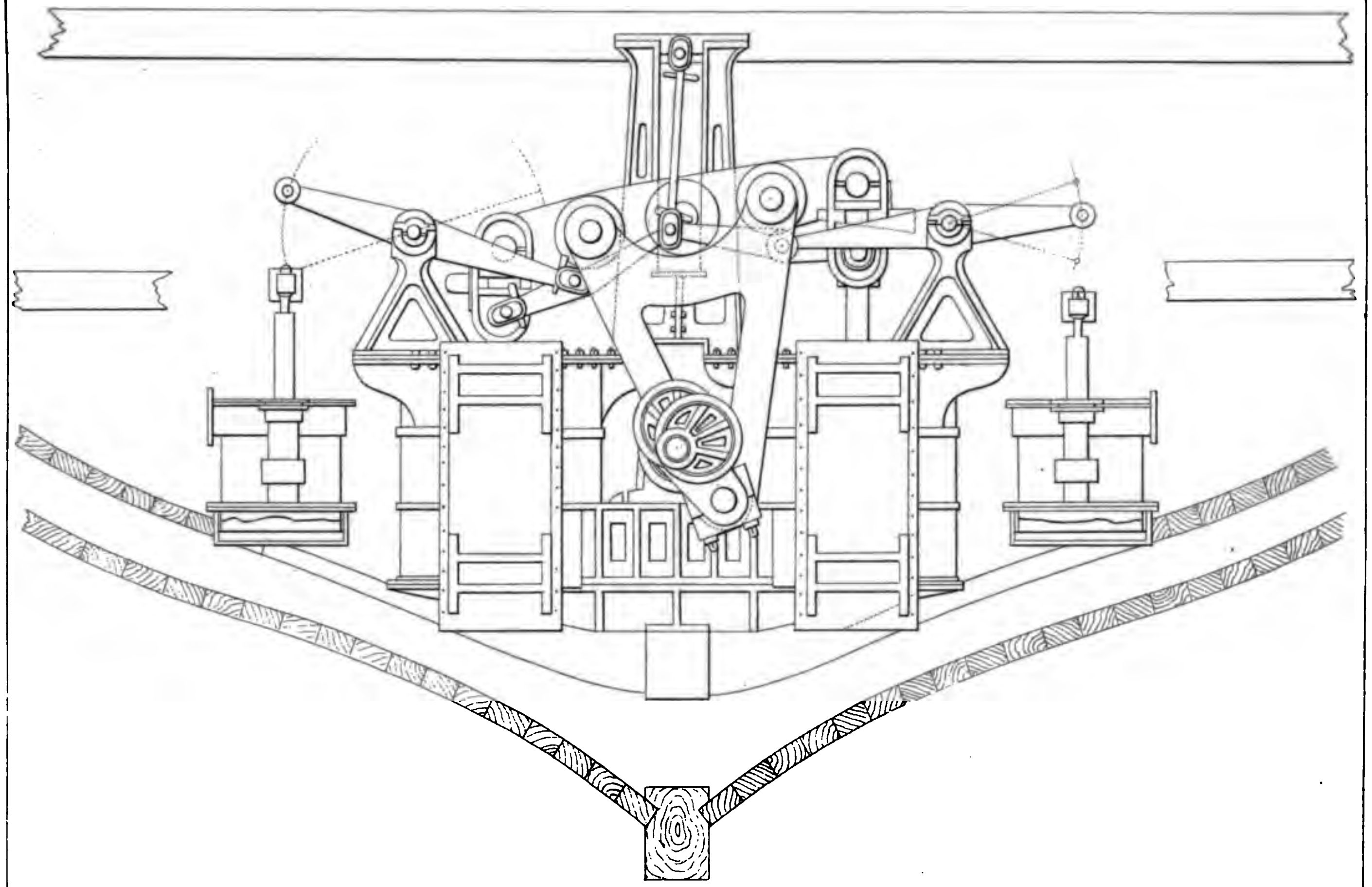


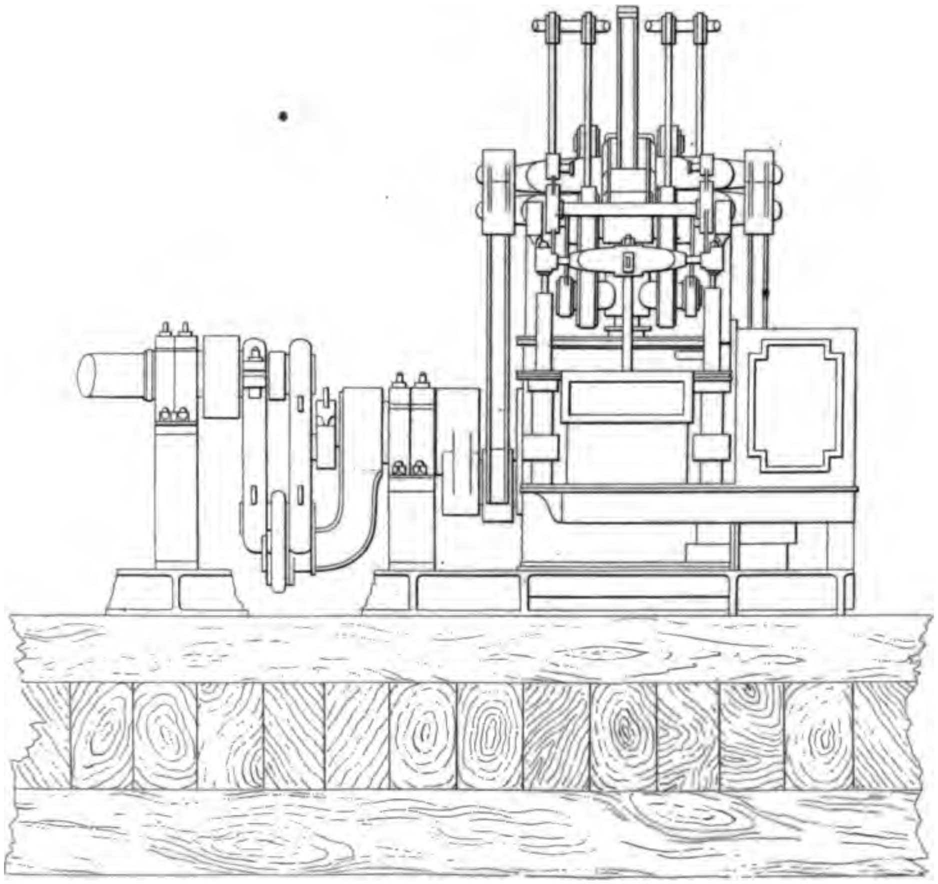
H. Adlard

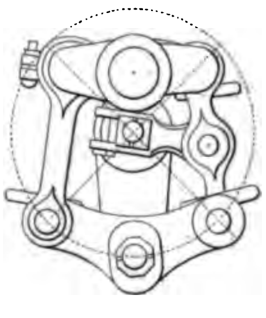
London Longman Brown &c. [illegible]

DIRECT ACTION ENGINES.

Designed by E Galloway for F P Smith.







H. Allard sc.

London, Longman, Brown, Green & Longmans.

PLATE XVII

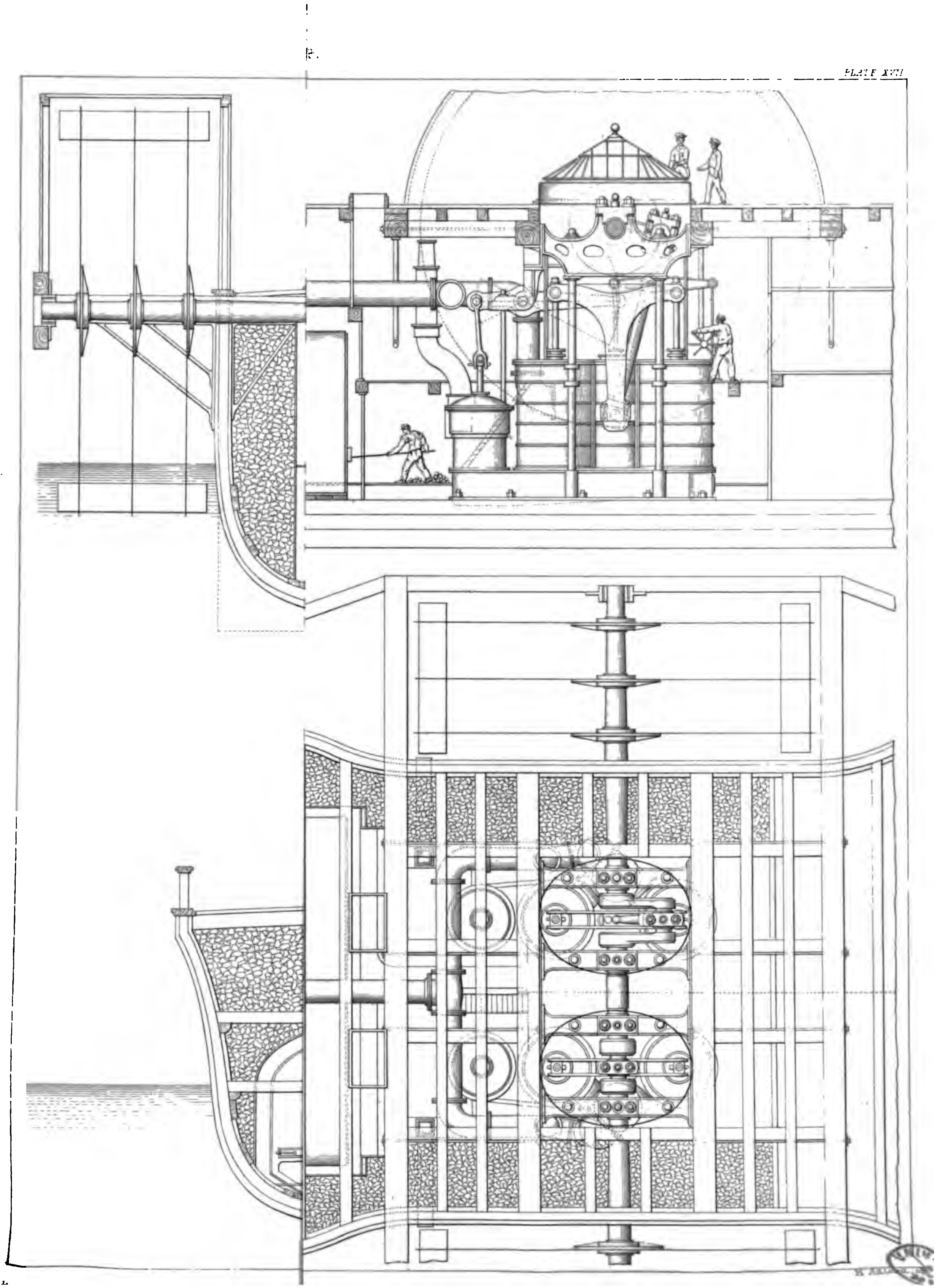
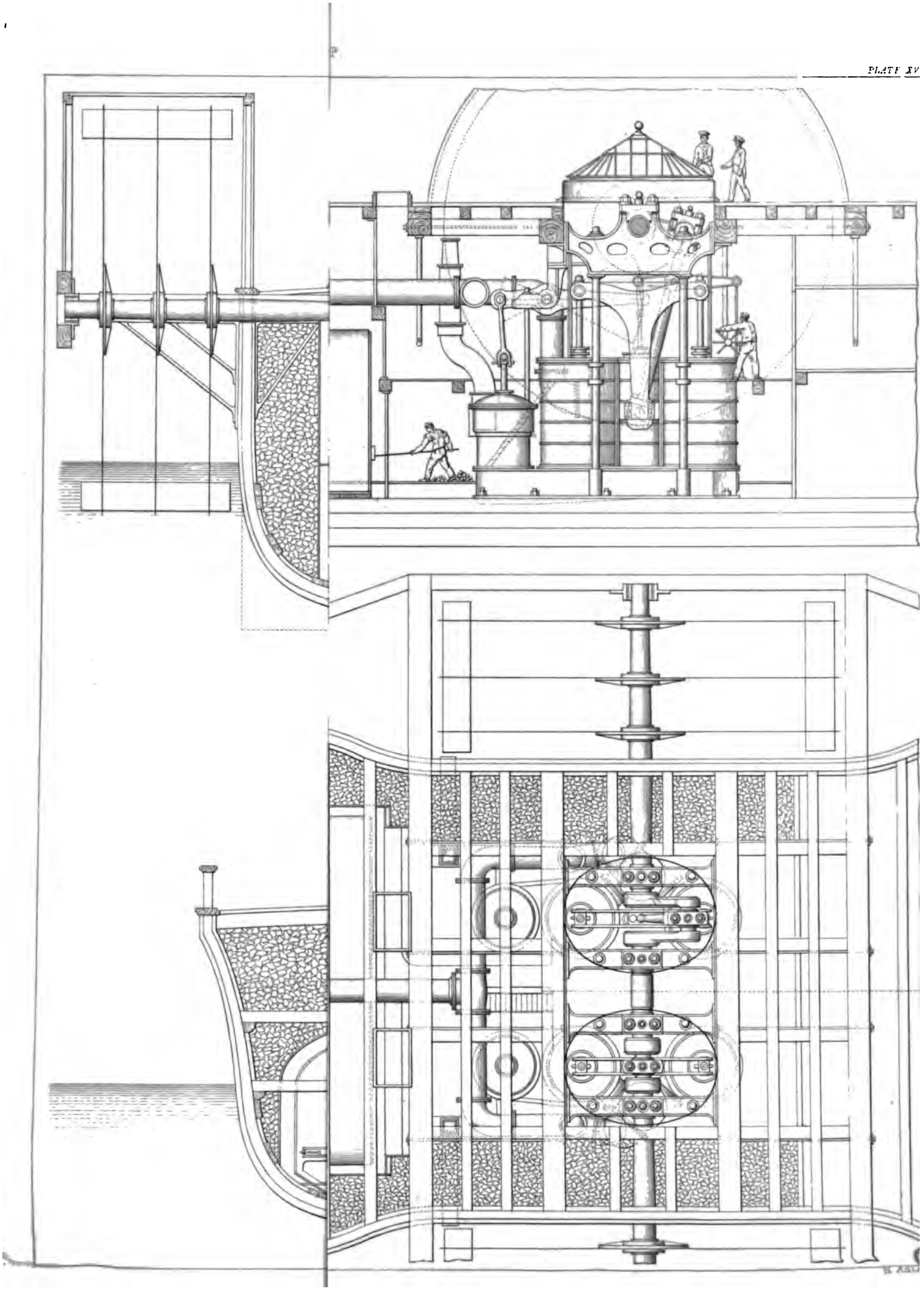
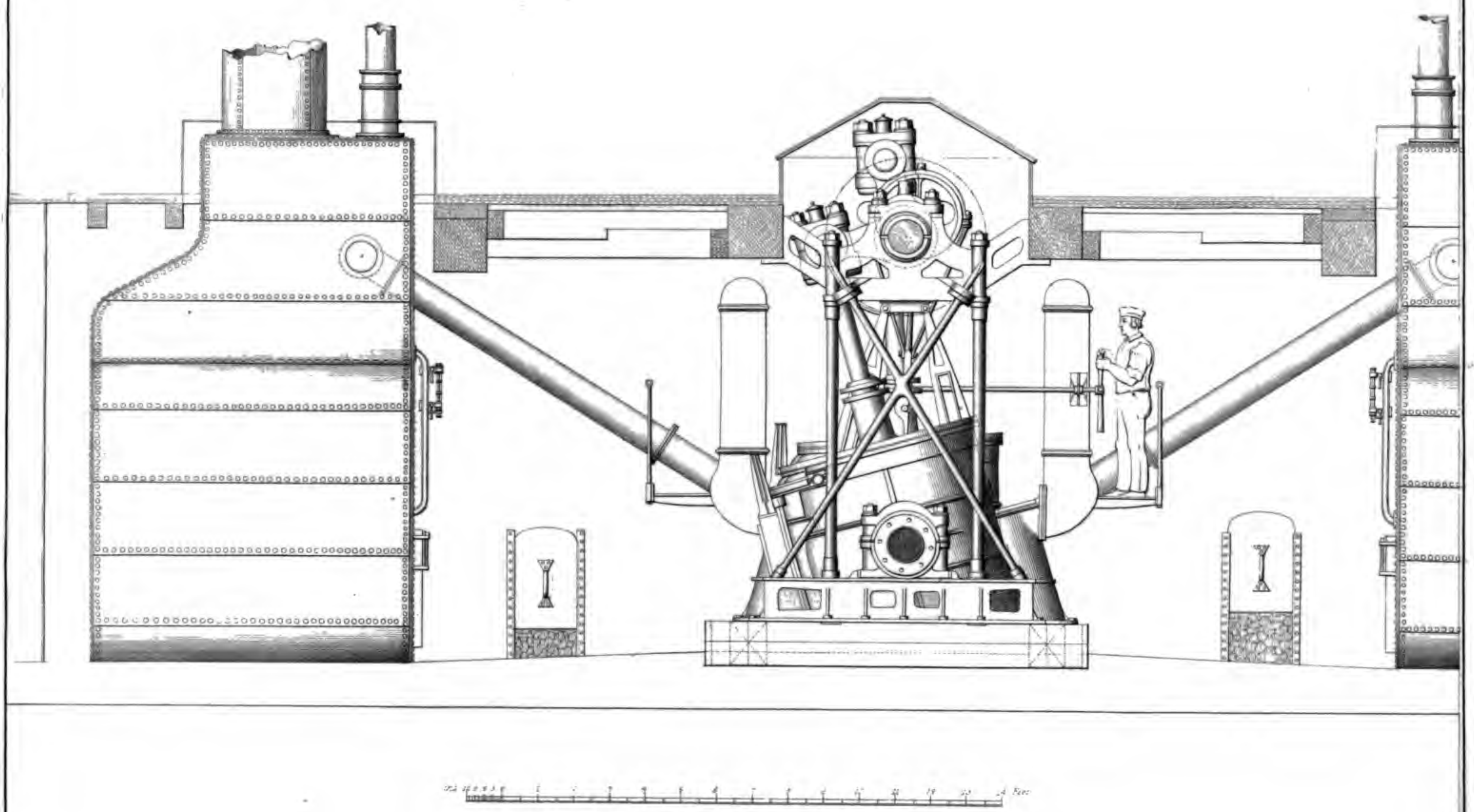


PLATE XV

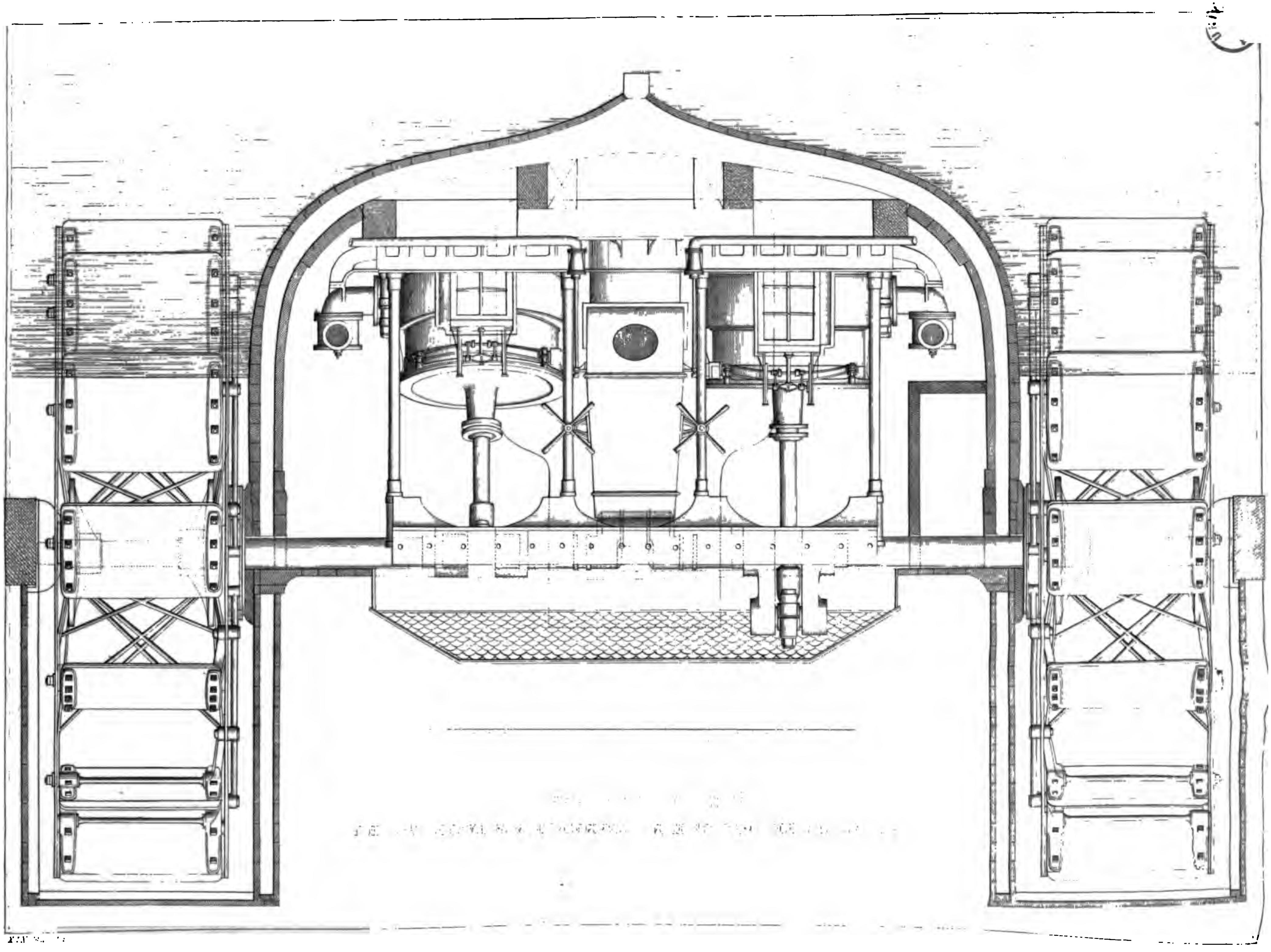


OSCILLATING ENGINES OF H.M. STEAMER, BLACK EAGLE, 260 H.P.

by Mess.rs Penn & Son, Greenwich



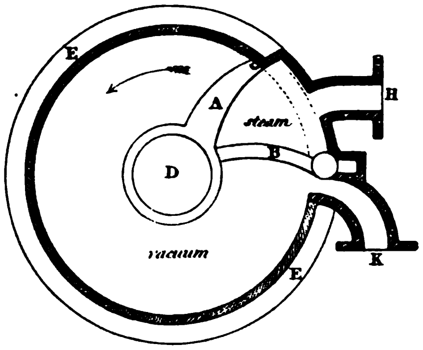
London: Longman, Brown, Green & Longmans.



PROJECTS for ROTATIVE STEAM ENGINES.

Mr Watt's. 1782.

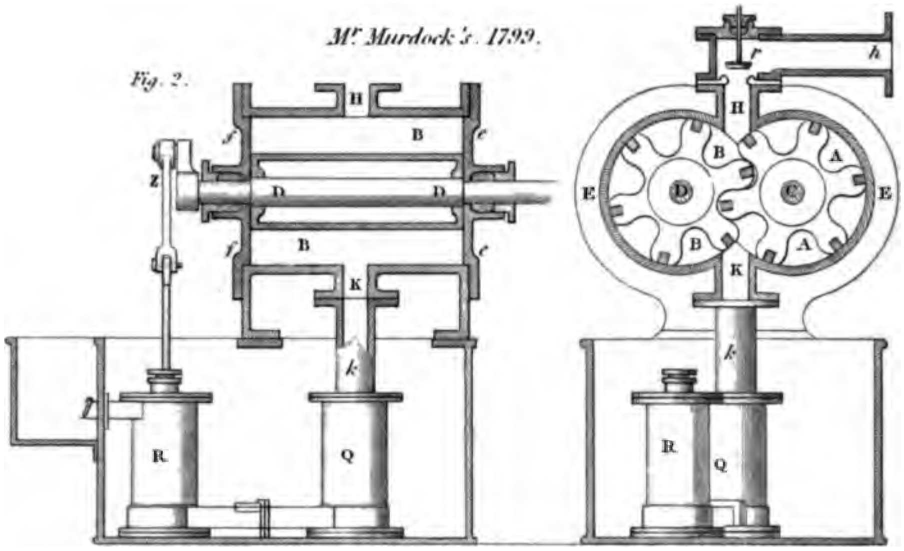
Fig. 1.



Mr Murdock's. 1799.

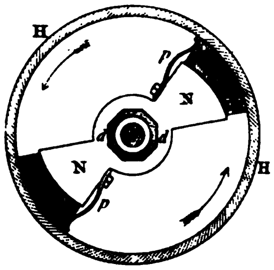
Fig. 2.

Fig. 3.



Mr Carter's. 1821.

Fig. 9.



Mr Hornblower's. 1798.

Fig. 5.

Fig. 6.

Fig. 7.

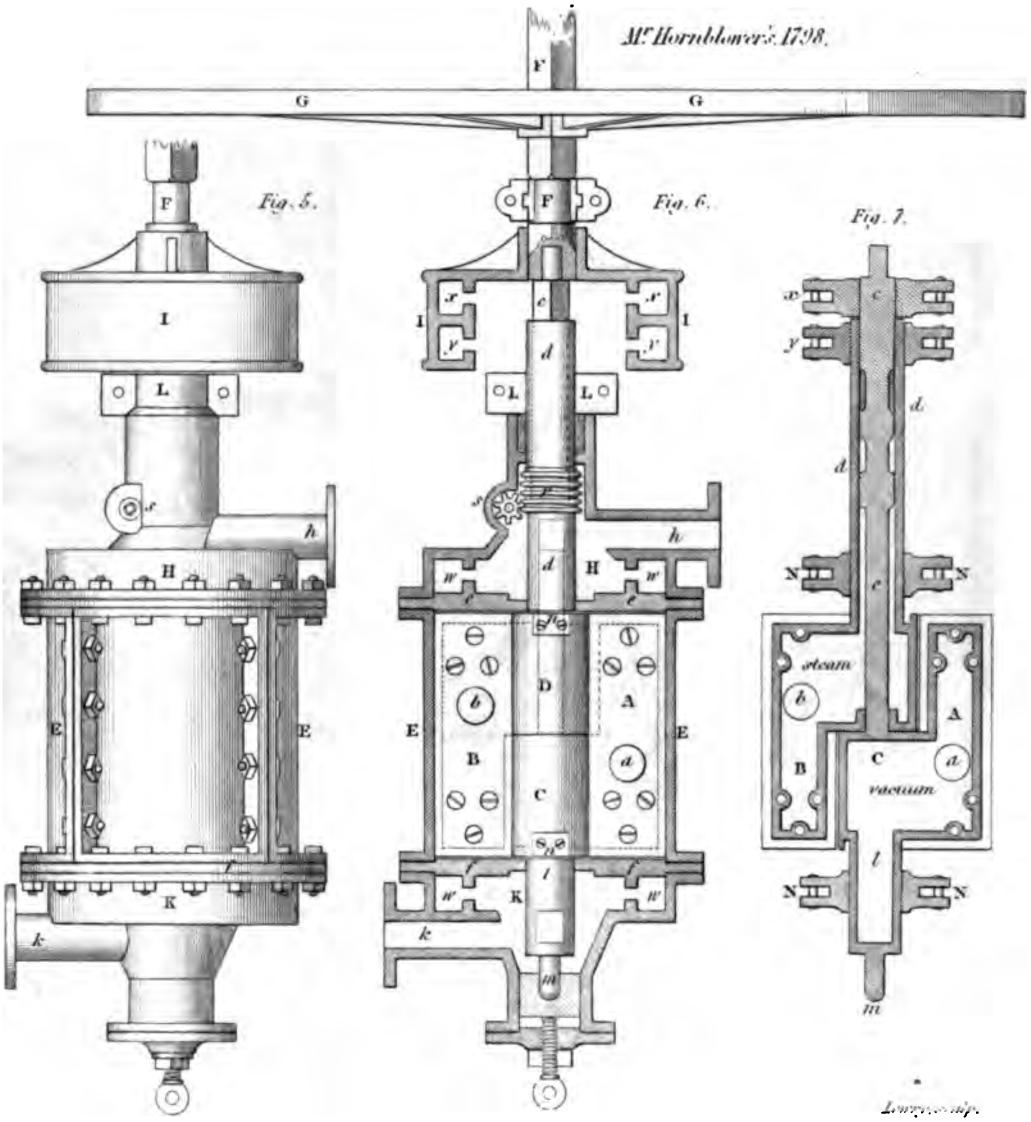


Fig. 4.

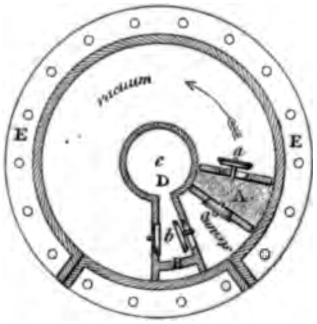
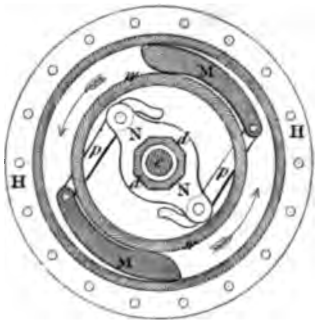


Fig. 8.



Farey. delin.

Lowry. sculp.

BORRIE'S REVOLVING ENGINE.

Fig. 2.

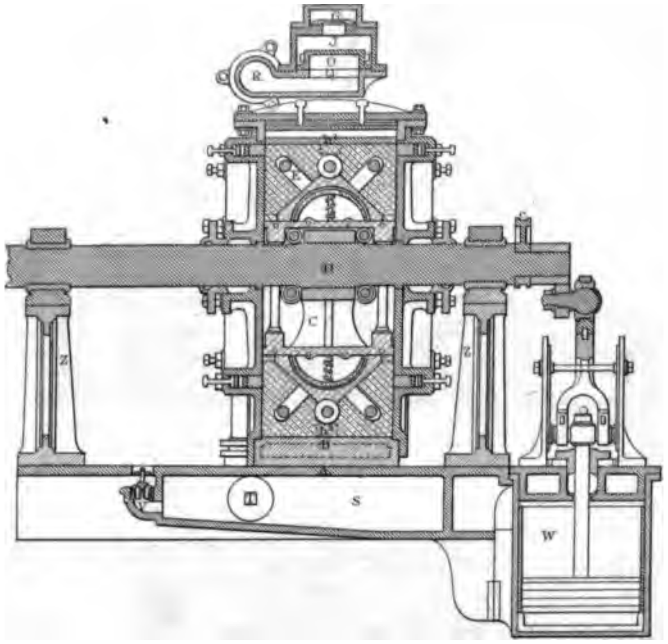


Fig. 3.

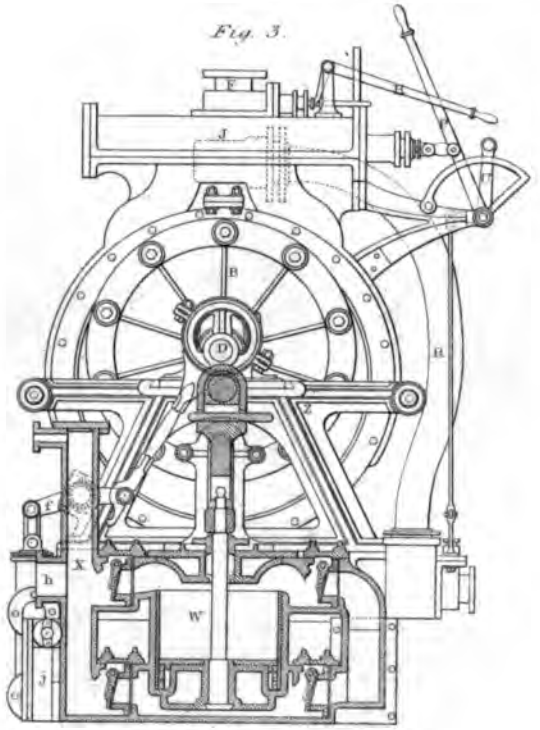


Fig. 1.

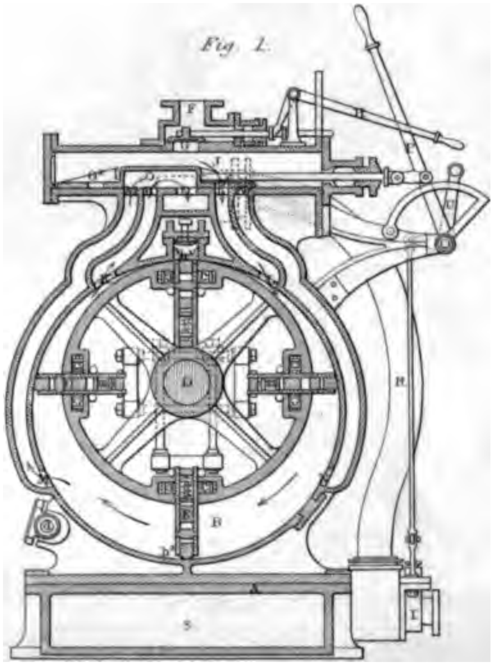


Fig. 4.

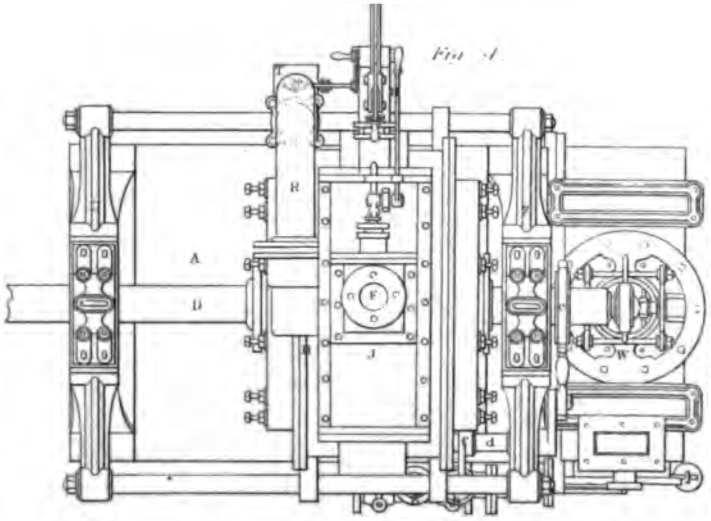


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Fig. 1.

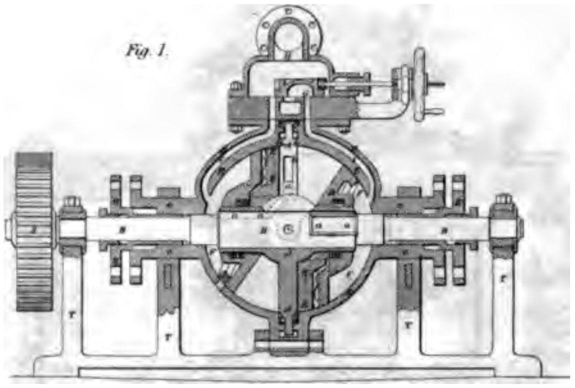


Fig. 3.

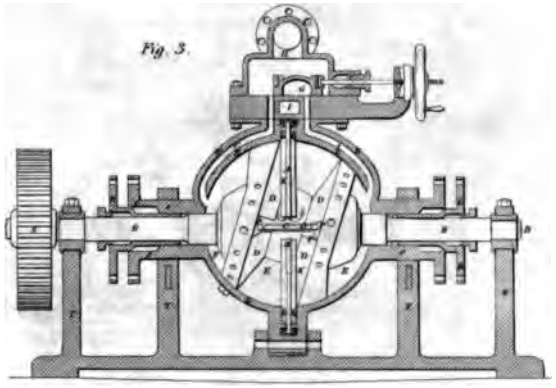


Fig. 2.

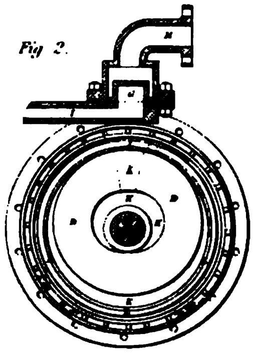


Fig. 4.

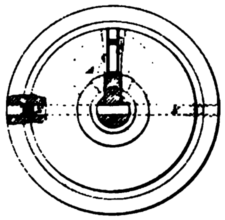


Fig. 5.

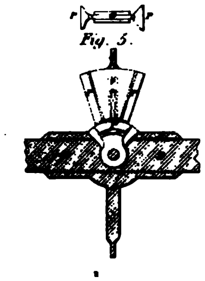


Fig. 8.

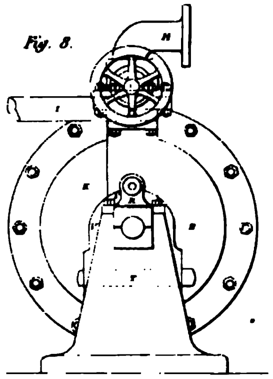


Fig. 6.

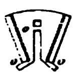


Fig. 7.

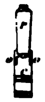
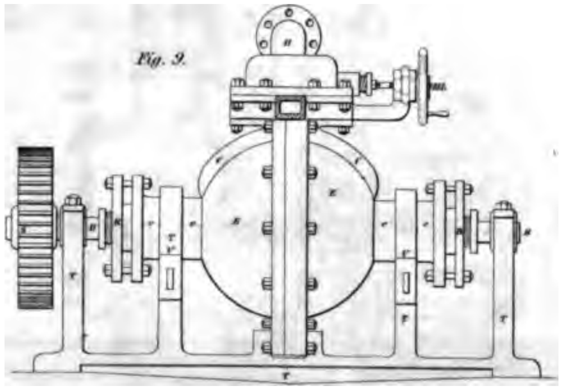


Fig. 9.



H. Adlard sc.

London: Longman, Brown, Green & Longmans [illegible]

PLATE XXI

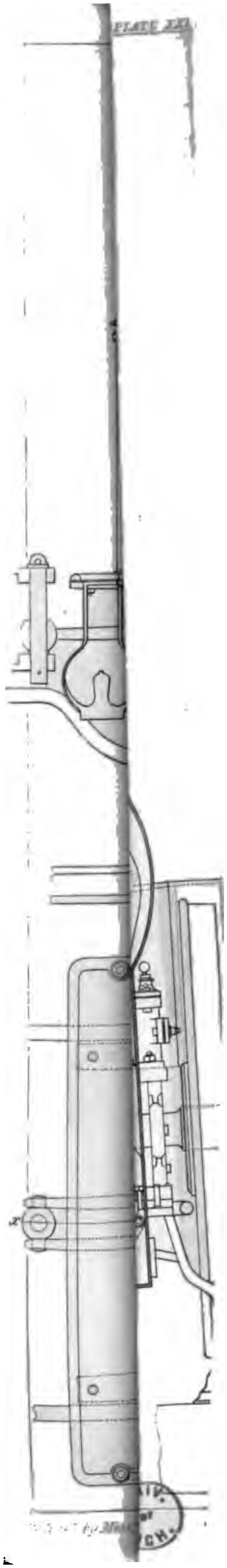
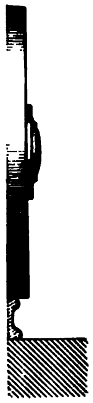


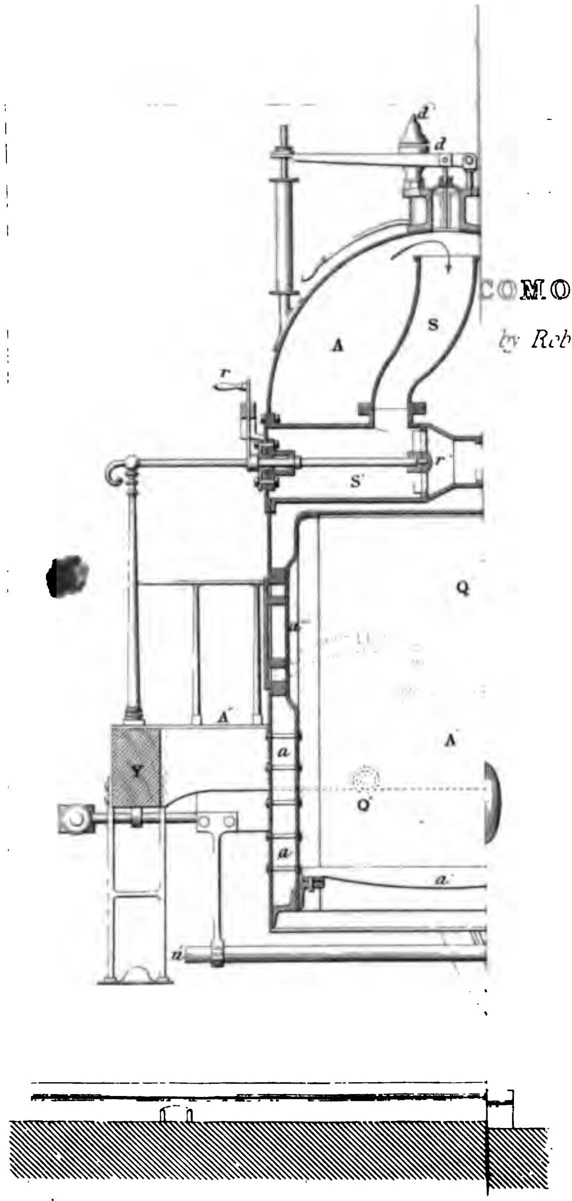
PLATE XXIV

SECTION

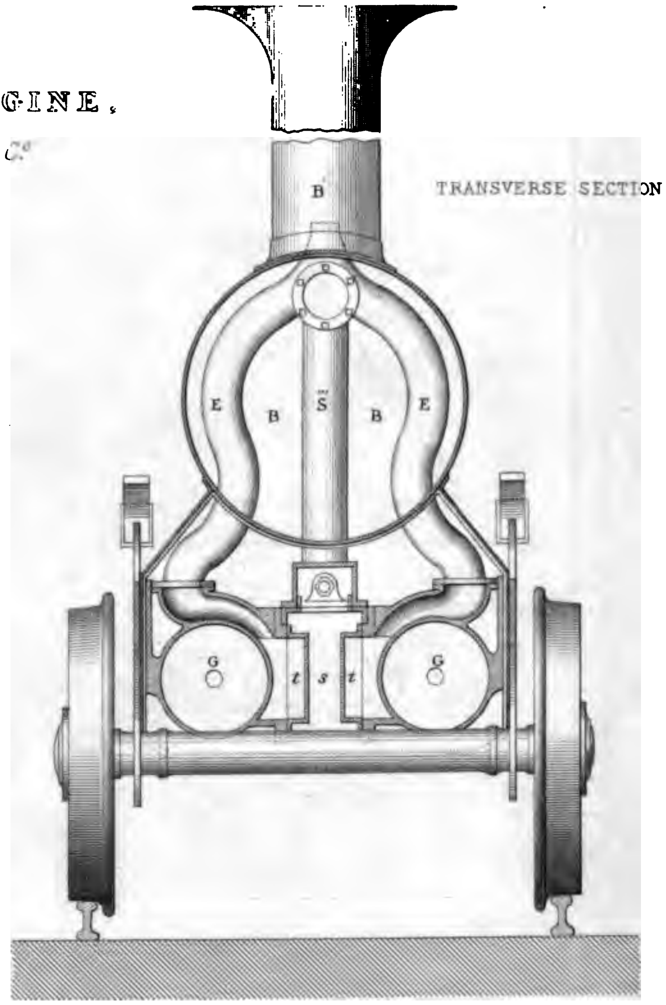


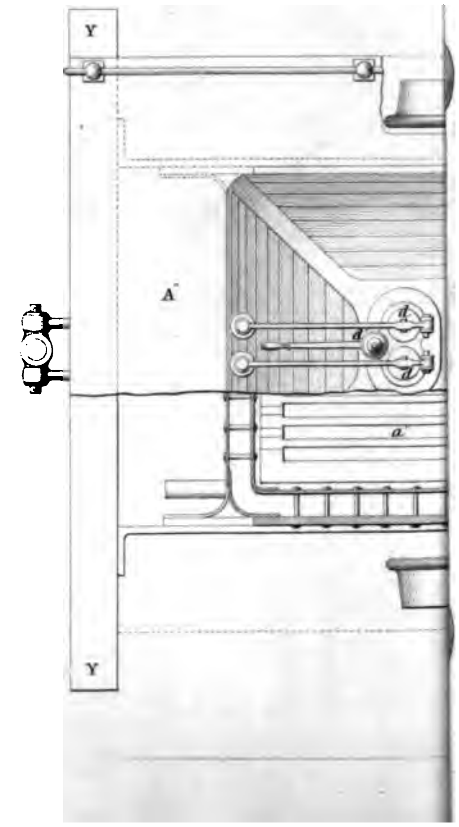
COMOTIVE ENGINE,

by Robert Stephenson & C.o

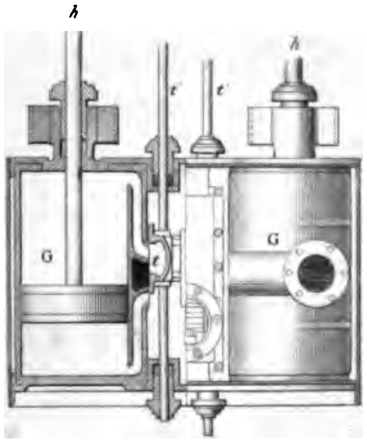


TRANSVERSE SECTION



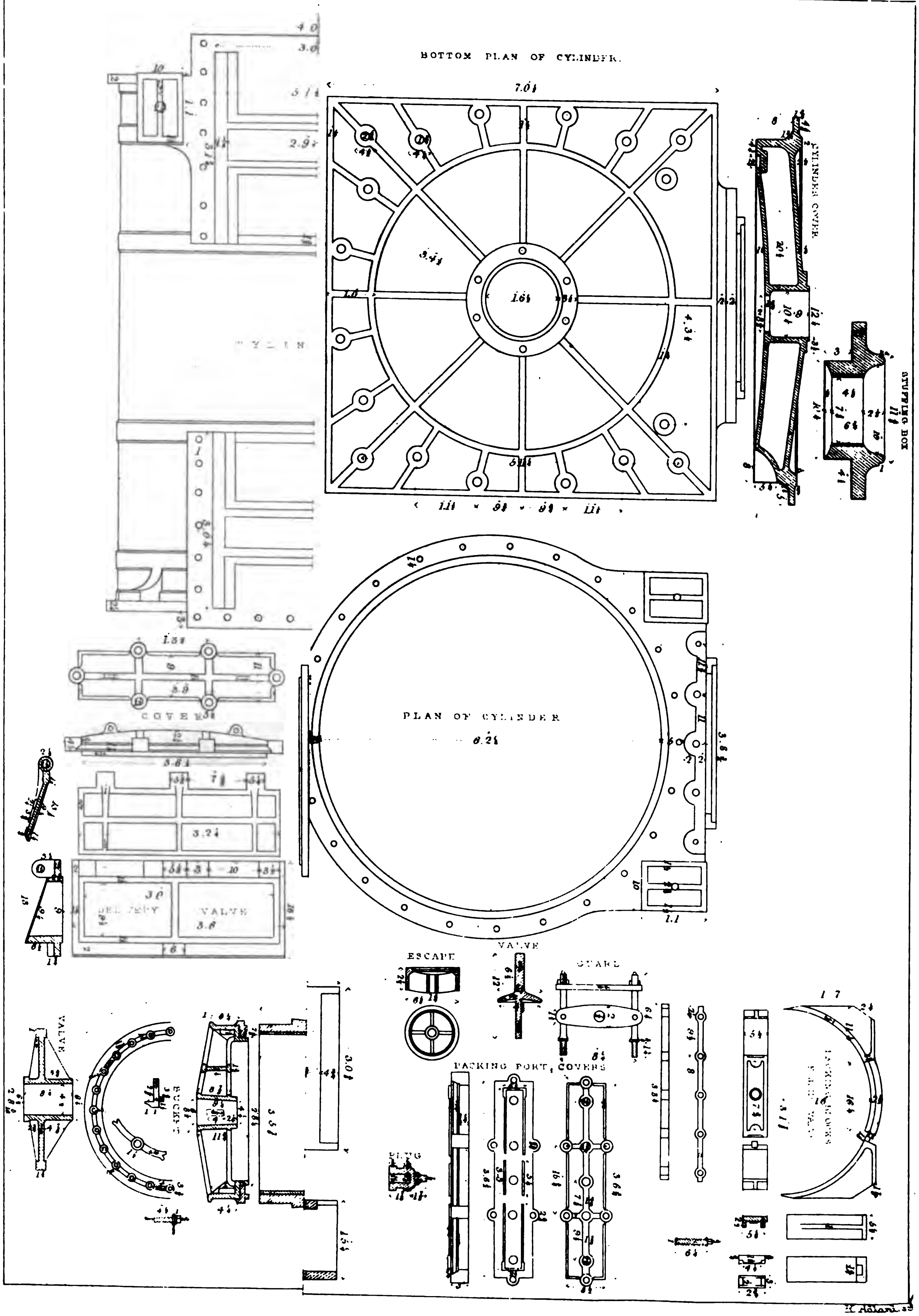


CYLINDERS AND VALVES

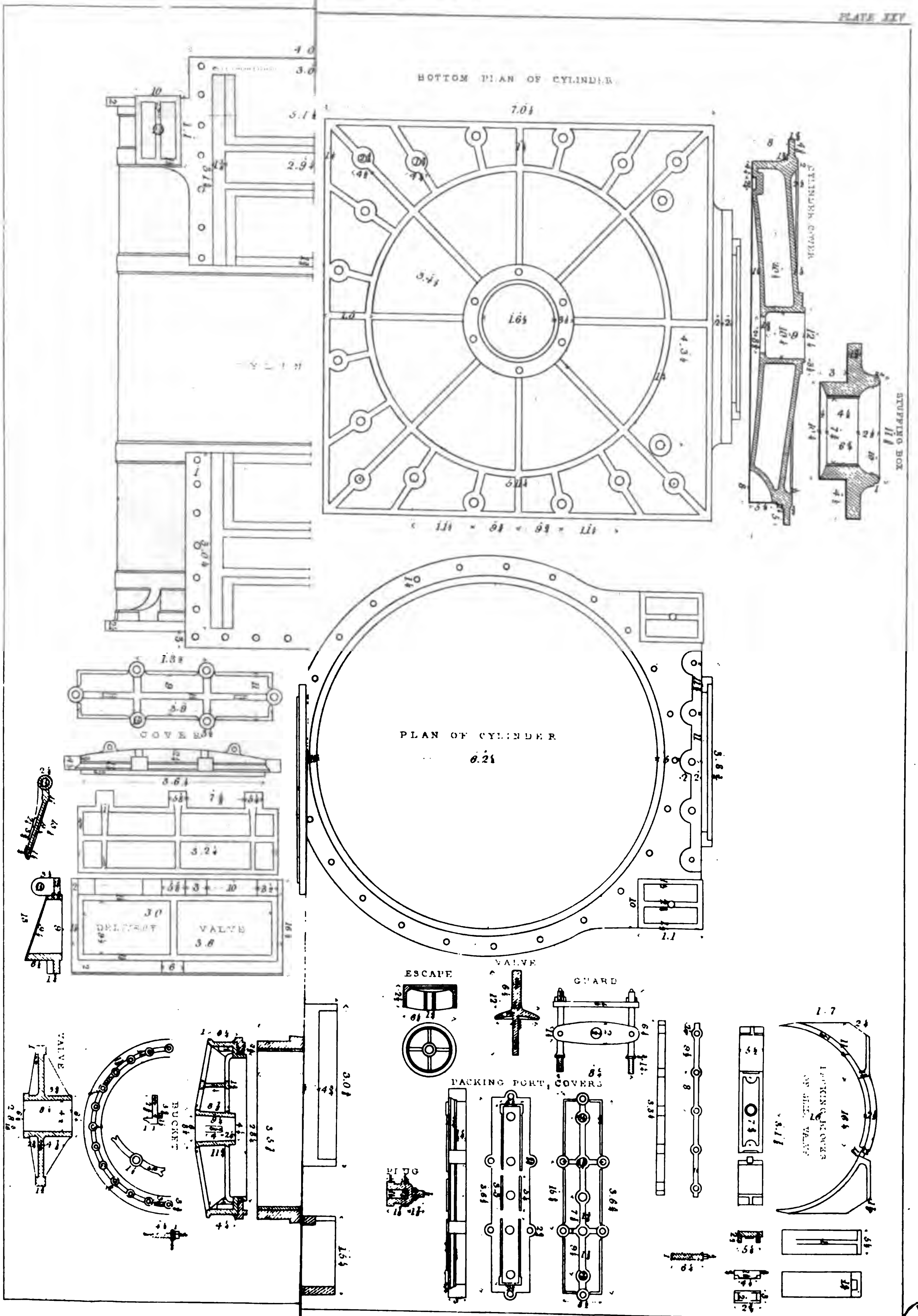


UNI

H. Adlard


BOTTOM PLAN OF CYLINDER.
7.0¼
1.6¼
4.3¼
CYLINDER COVER
STUFFING BOX
PLAN OF CYLINDER
6.2¼
COVER
3.6¼
3.2¼
DELIVERY
VALVE
3.6
VALVE
BUCKET
ESCAPE
VALVE
GUARD
PACKING PORT, COVERS
PLUG
3.0¼
3.5¼
1.5¼
3.6¼
1 7

H. Adlard sc

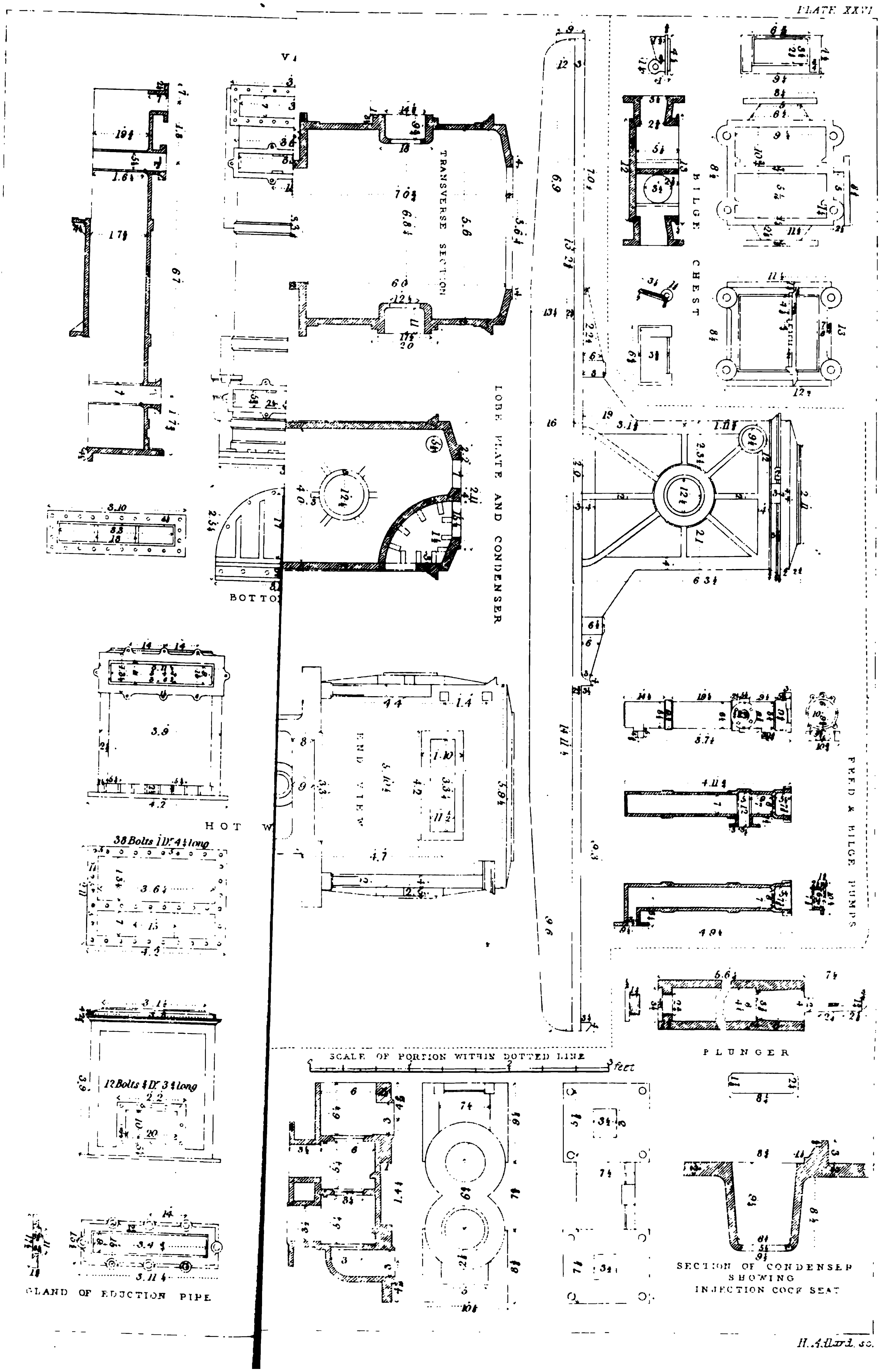


H. Adlard sc.

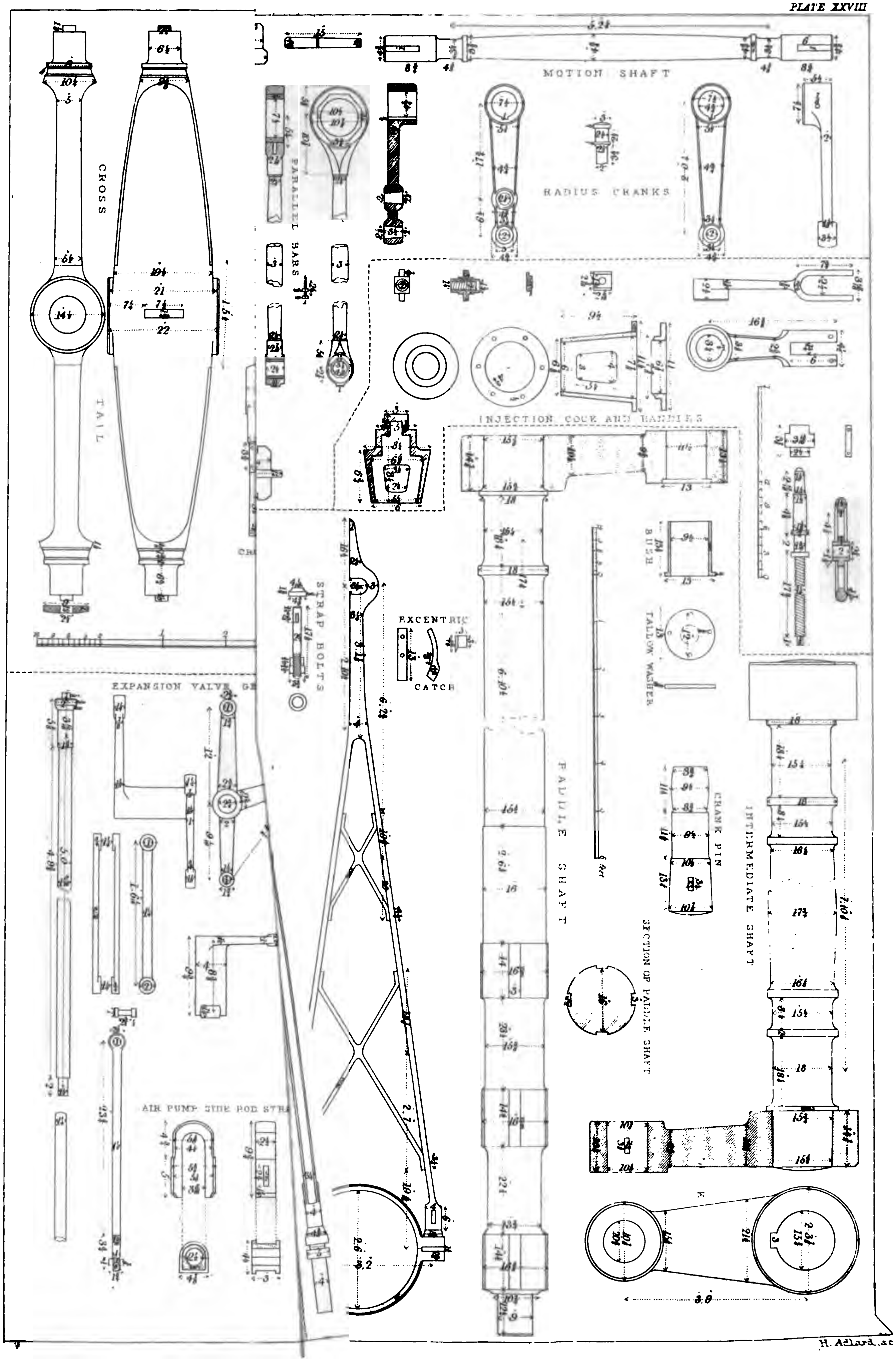
UNI

TEVIOT. (2)

PLATE XXVI



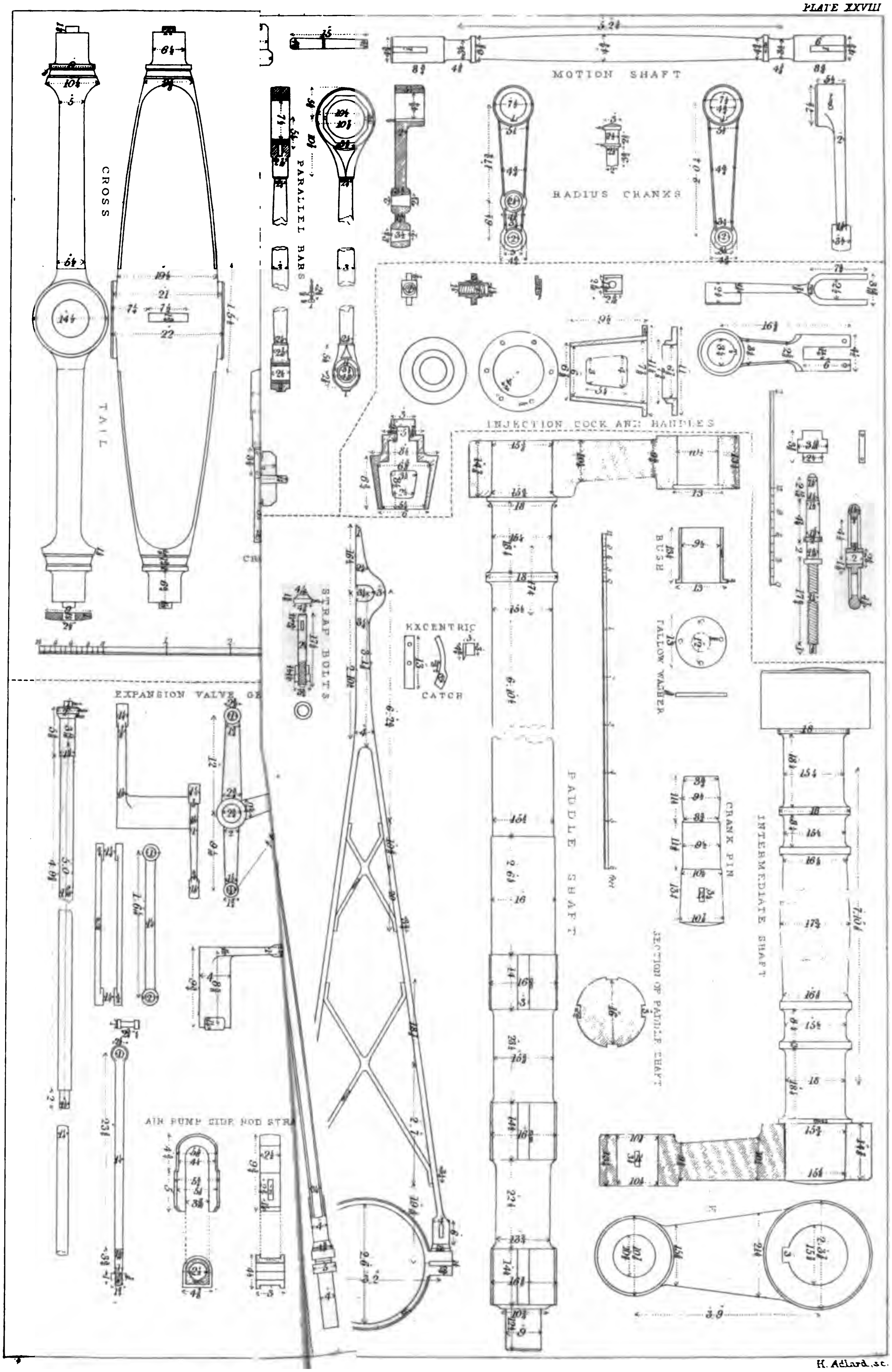
H. Adlard, sc.


CROSS
TAIL
PARALLEL BARS
MOTION SHAFT
RADIUS CRANKS
INJECTION COCK AND HANDLES
EXPANSION VALVE GE
STRAP BOLTS
EXCENTRIC
CATCH
PADDLE SHAFT
BUSH
TALLOW WASHER
CRANK PIN
SECTION OF PADDLE SHAFT
INTERMEDIATE SHAFT
AIR PUMP SIDE ROD STR
CR

H. Adlard, sc

Y & TEVIOT. (4)

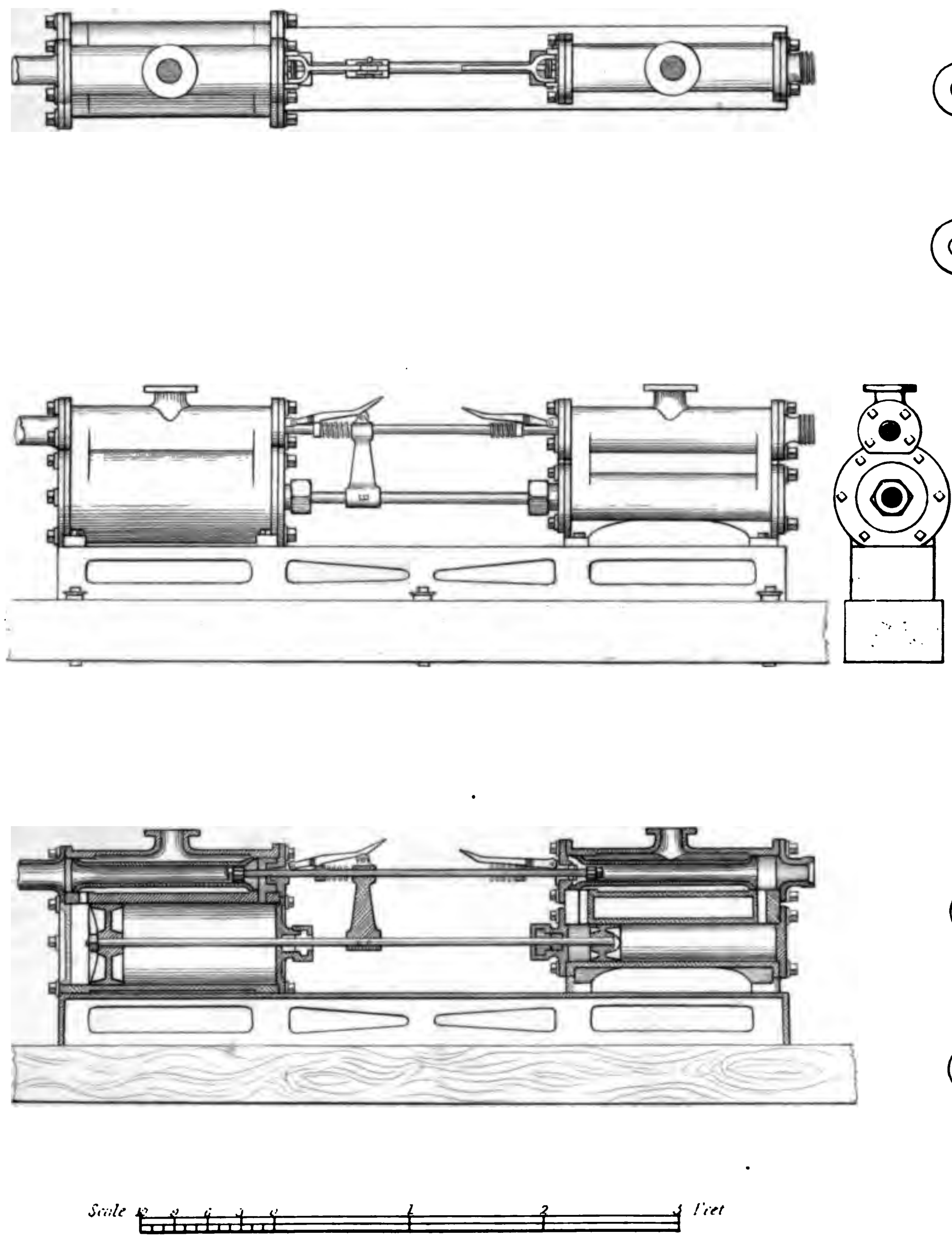
PLATE XXVIII

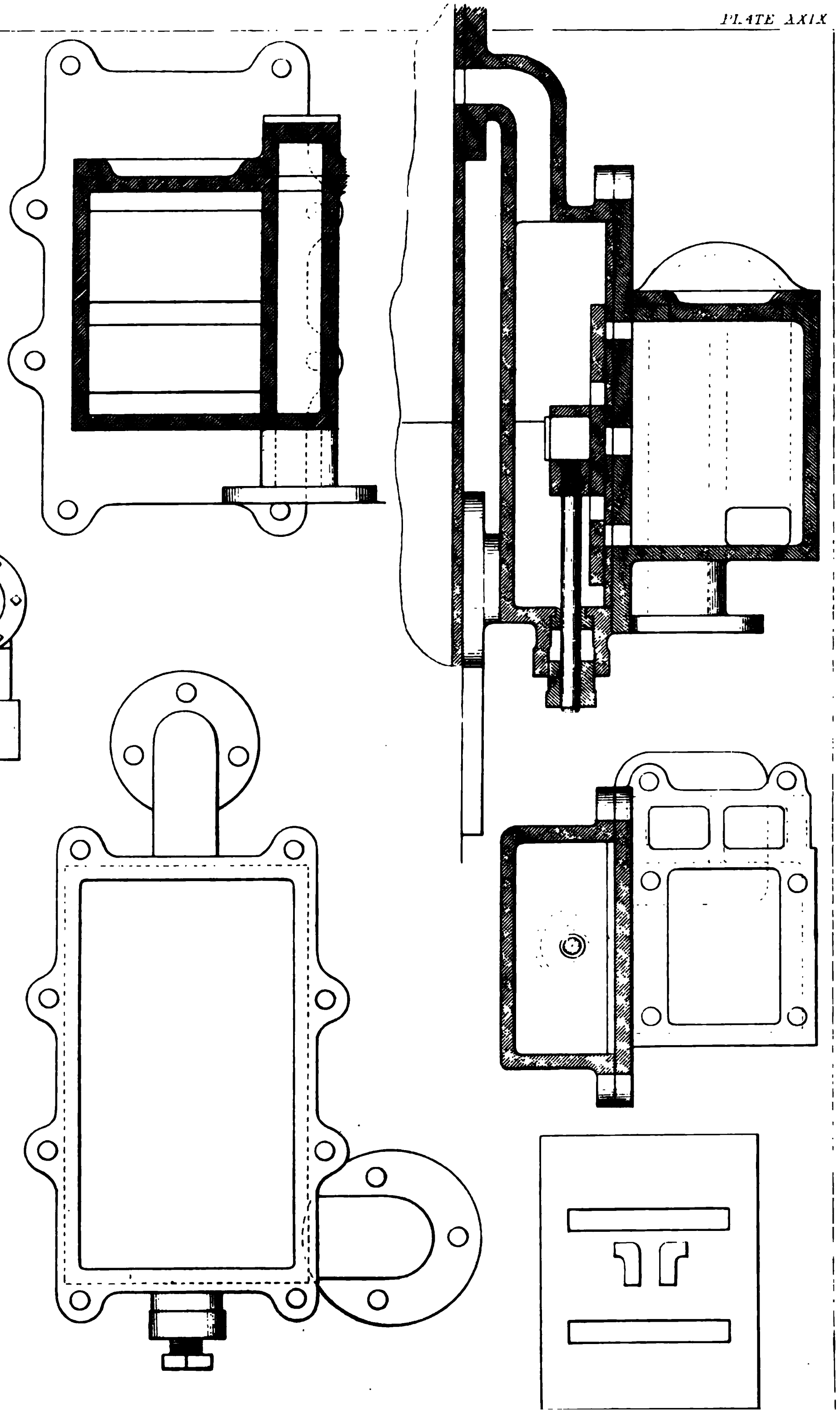


H. Adlard, sc.

FEED ENGINE, FOR MARINE BOILERS.

John Penn, Greenwich.





UNIV. OF WIS.